BARRY'S INTRODUCTION TO CONSTRUCTION OF BUILDINGS

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and

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Contents

Preface

Robin Barry's *The Construction of Buildings* was first published in 1958. The books quickly became an established source of information for students of building design and construction, with their popularity demonstrated in numerous reprints and revised editions. Since the late 1950s we have seen many changes in construction technology and the manner in which buildings are designed and constructed, some of which have been little more than passing fashions, many of which have had a lasting impact. Although some of our buildings may look very similar to those built in the past, the reality is that buildings are now built to higher performance standards and have to comply with far more extensive legislation than ever before. With the desire to build faster, cheaper and to higher standards we have seen a shift in emphasis from the building site to off-site production in remote factories, a growing trend, but one that is by no means universal. Currently it is possible to find highly industrialised processes sitting, quite literally, next to craft based activities and also to find new products and materials being used in conjunction with those that have been used for centuries. We have also started to develop a better awareness of the environmental impact both of construction activities and the building in use, combined with increased emphasis on the health and wellbeing of building users. When combined, these factors help to colour our approach to the construction of buildings and for students and practitioners alike these are exciting times.

In an attempt to reflect these changes and assist students in their studies we have embarked on a major revision of the Barry series. More specifically, we have revised the series in the light of changes to building regulations, standards and codes, changes in technologies and increased concern for the environmental impact of construction. In doing so we felt that we should re-design the five volume series and present it as a discrete two-volume set: *Barry's Introduction to Construction of Buildings* (previously *Barry 1, 2* and part of *5*) and *Barry's Advanced Construction of Buildings* (previously *Barry 3, 4* and part of *5*). The rationale behind using the words 'introduction' and 'advanced' is grounded in a recognition of how construction technology is taught in universities and colleges, with this volume addressed primarily to first year (Level 1) students and the advanced volume (currently in production) to second year (Level 2) students. Barry's original concept was based on the sound principle of introducing key functional/performance requirements for the main elements common to all buildings: a concept that has been maintained here, and an approach now common to the UK's building regulations. As part of the major update of

the Barry series we have provided typical details and alternative approaches (where applicable), thus ensuring that the series is topical and relevant for work to new and existing buildings. We have also included photographs from construction sites in an attempt to further the understanding of the technologies described.

We are acutely aware of the fact that the Barry series can only deal with a limited range of 'concrete' issues. As such these two books provide an overview of construction methods that are intended as guidance for students learning the fundamentals of building construction. We are also conscious that this is an ongoing project and would welcome comments and suggestions for future editions. We hope that the spirit of the Barry series continues to inform and stimulate those interested and engaged in the construction of buildings.

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Acknowledgements

1 Introduction

The aim of this short introductory chapter is to highlight some of the factors that determine how buildings are constructed and also to provide some context to the chapters that follow. An overview of the function and performance of buildings leads into a discussion about the basic principles of construction. The chapter concludes with some comments on legislation, making choices and sources of additional information.

1.1 The function and performance of buildings

Buildings are constructed, altered, upgraded, restored or demolished for a variety of reasons. Whether the aim is simply to provide more space or to make a financial gain from speculative development, all building projects need to fulfil a function and meet set performance requirements, no matter how fundamental or sophisticated the client's requirements may be.

Function

The primary function of a building is to provide shelter from our weather, a container for living, working and playing in. The principal functional requirements include:

- ❏ shelter
- ❏ security
- ❏ safety (and comfort)
- ❏ ease of use and operation (functionality)
- ❏ ease of maintenance, periodic repair and replacement
- ❏ adaptability and durability
- ❏ ability to recycle materials and components

The overall goal is to achieve these functions in an economical, safe and timely fashion using the most appropriate resources available.

Performance

The performance of the building will be determined by a number of inter-related factors set by the client, legislation and society. Clients' performance

requirements will vary from project to project. However, the main considerations are likely to be:

❑ space, determined by a figure for floor area and/or volume
❑ thermal and acoustic performance
❑ design life and service life of the building and specific building elements
❑ cost of construction, cost in use and cost of demolition and recycling
❑ quality of the finished building
❑ appearance of the finished building

Other specific performance criteria will relate to the use of the building, for example the provision of special work surfaces for catering establishments. Legislative performance requirements are set out in building codes and regulations (see below). Specific performance requirements are given for certain areas, for example the thermal insulation of walls and fire protection of doors, and these must be met or bettered in the proposed construction method.

Design and constructability

The functional and performance requirements will inform the design process, from the initial concepts right through to the completion of the details and production of the information (drawings, schedules and specifications) from which the building will be constructed. The design of the junction between different materials, i.e. the solution for how different parts are assembled, is crucial in helping to meet the performance and functional requirements of the overall building. Good detailing will help the contractor to assemble the building safely and economically and will contribute to the durability and ease of use of the building over its life.

Constructability (or buildability) is an approach to building design and construction that seeks to eliminate non-productive work on site, make the production process simpler and provide the opportunity for more efficient site management and safer working. Thus designing and detailing for constructability requires an understanding of how components are manufactured off site, as well as how the building is to be assembled (the sequence of work packages) on the site. The core message of constructability is more simplicity, greater standardisation, and better communication between designer, manufacturer and builder. These three principles also relate to the eventual disassembly of the building at some date in the future when materials will be recovered, reused and recycled, hopefully with minimal waste. Some of the practical considerations are concerned with:

❑ Time scale
❑ Availability of labour and materials (supply chain logistics)
❑ Sequence of construction and tolerances

❑ Reduction of waste (labour, materials and time)
❑ Protection from the weather
❑ Integration of structure, fabric and services
❑ Maintenance and replacement
❑ Disassembly and recycling strategies

Quality

The quality of the completed building, as well as the process that brings it about, will be determined by the quality of thought behind the design process, the quality of the materials and products specified and the quality of the work undertaken. There are a number of different quality issues:

(1) Quality control is a managerial tool that ensures both work and products conform to predetermined performance specifications. Getting the performance specification right is an important step in getting the required quality, be it for an individual component or the whole building.
(2) Quality assurance is a managerial system that ensures quality service to predetermined parameters. The ethos of total quality management aims at continual improvement and greater integration through a focus on client satisfaction. Manufacturers, contractors and professional consultants use this.
(3) Quality of the finished artefact will be determined by a number of variables constant for all projects, namely the:
    ○ interaction and characteristics of the participants engaged in design, manufacture and assembly
    ○ effectiveness of the briefing process
    ○ effectiveness of the design decision-making process and resultant information
    ○ effectiveness of the assembly process
    ○ effectiveness of communications
    ○ time constraints
    ○ financial constraints
    ○ manner in which users perceive their built environment

The required quality of materials and workmanship will be set out in the written specification. Good quality materials and good quality work tend to carry a higher initial cost than lower quality alternatives; however, the overall feel of the building and its long-term durability may be considerably improved: we tend get what we pay for. When making decisions about the materials and components to be used it is important to consider the whole life cost of the materials, not just their initial capital cost and the cost of labour to assemble the materials.

Economics

The building site and the structures constructed on the land are economic assets. In addition to the cost of the land there are three inter-related costs to consider. The first is the initial cost, the cost of designing and erecting the building. This is usually the primary, and sometimes the only concern of clients and developers. It covers professional fees and associated costs involved in land acquisition and permissions, the capital cost of materials and components and the labour costs associated with carrying out the work.

The second cost to consider is the cost of the building in use, i.e. the costs associated with routine maintenance and replacement and the costs associated with heating and servicing the building over its life. These costs can be reduced by sensitive design and detailing, for example designing a building to use zero energy and to be easy to maintain will carry significant cost benefits over the longer term (not to mention benefits to the environment). All materials and components have a specified design life and should also have a specified service life. Designers and contractors need to be aware of these factors before starting work, thus helping to reduce defects and maintenance requirements before construction commences.

The third cost is the cost of materials recovery at the end of the life of the building, i.e. the cost of demolition, recycling and disposal. All three areas of cost associated with building should be considered within a whole life cost model, from which decisions can be made about the type of materials and components to be used and the manner in which they are to be assembled (and subsequently disassembled). This links with issues concerning maintenance, repair renovation and recycling.

Construction defects

Despite everyone's best intentions it is likely that some faults and defects will be found in the completed building. Some of these will be evident at the completion of the contract, others may not reveal themselves until some time in the future and are known as 'latent defects'. We can, for simplicity, divide defects into two categories: those concerning products and those associated with the process of design and construction.

Product defects

With the constant drive to improve the quality of materials and building components from the manufacturing sector it is unlikely that there will be a problem with building products; assuming that they have been carefully selected, specified correctly and assembled in accordance with the manufacturers' instructions. Reputable manufacturers have adopted stringent quality control and quality management tools to ensure that their products are consistently of a specified quality, are delivered to site to programme and technical support is available as required. A well-written performance specification or a carefully

selected proprietary specification, combined with careful implementation on site should help to reduce or even eliminate product related defects. Problems can usually be traced back to hastily prepared specifications, cost cutting and specification of lesser quality products, and/or poor practice on the building site. Products recently launched on to the market and to a lesser extent products new to a particular design office carry an increased degree of uncertainty over their performance, and hence a perceived increase in risk.

Process defects
Problems with the process of design and construction are the most likely cause of defects. The design and construction process, regardless of the degree of automation, relies on people to make decisions and to implement the result of those decisions. Designers record and communicate their decisions primarily through drawings and the written specification. Thus the quality of the information and the timing of the delivery of the completed information (i.e. communication) will influence the likelihood of defects occurring. Quality of work on site will depend on the interpretation of the information provided, control and monitoring of the work. Design changes, especially during construction may cause problems with constructability and subsequent maintenance. If a fault or defect is discovered then it needs to be recorded, reported and appropriate action agreed to correct the defect without undue delay.

1.2 General principles of construction

Whatever approach we take to the design and erection of our buildings there are a number of fundamental principles that hold true. The building has to resist gravity and hence remain safe throughout its design life and substantial advice is provided in regulations and standards. Every building is composed of some common elements:

❑ Foundations (see Chapters 2 and 3)
❑ Floors (see Chapter 4)
❑ Walls (see Chapter 5)
❑ Roof (see Chapter 6)
❑ Windows and doors (see Chapters 7 and 8)
❑ Stairs and ramps (see Chapter 9)
❑ Surface finishes (see Chapter 10)
❑ Services (see Chapter 11 and 12)

It is vital for the success of the building project and the use of the constructed building that an integrated approach is adopted. It is impossible to consider the choice of, for example, a window without considering its interaction with the wall in which it is to be positioned and fixed.

Loadbearing construction

Masonry loadbearing construction is well established in the British building sector and despite a move towards more prefabrication, loadbearing construction tends to be the preferred option for many house builders and small commercial buildings (see Chapter 5). There is a heavy reliance on the skills of the site workers and on wet trades, e.g. bricklaying, plastering, etc. Quality control is highly dependent upon the labour used and the quality of the supervision on site.

In a typical loadbearing cavity wall construction the main loads are transferred to the foundations via the internal loadbearing wall. The external skin serves to provide weather protection and aesthetic quality. Primarily 'wet' construction techniques are employed.

Framed construction

Framed construction has a long pedigree in the UK, starting with the framed construction of low rise buildings from timber and followed by early experiments with iron and reinforced concrete frames. Subsequent development of technologies and industrial production have resulted in three main materials being used for low-rise developments: timber, steel and concrete. Framed construction is better suited to pre-fabrication and off-site manufacturing than masonry loadbearing construction. Dry techniques are used and quality control is easier because the production process is repetitive and a large amount of the work is carried out in a carefully controlled environment. Site operations are concerned with the correct placement and connection of individual component parts in a safe and timely manner.

In a typical framed cavity wall construction the main loads are transferred to the foundations via the structural frame. The external skin serves to provide weather protection and aesthetic quality. It is common in England to clad timber and steel framed buildings with brickwork, thus from external appearances it may be impossible to determine whether the construction is framed or loadbearing (see Photograph 1.1).

Pre-fabrication and off-site production

Post-Egan the emphasis is firmly on pre-fabrication and off-site production. This is, of course, only one of many different approaches and is usually more suited to repeat building types than one-off projects. However, the range of prefabricated units is expanding and considerable improvements in product quality and health and safety may be made through the use of prefabricated components and proprietary systems. This has tended to move the skills away from the building site into the controlled environment of the factory. Site operations become limited to the lifting, positioning and fixing of components into the correct position and emphasis is on delivery of components to site 'just in

Timber frame completed up to first floor

Timber frame completed up to second floor

Timber frame house complete with brick cladding

A

B
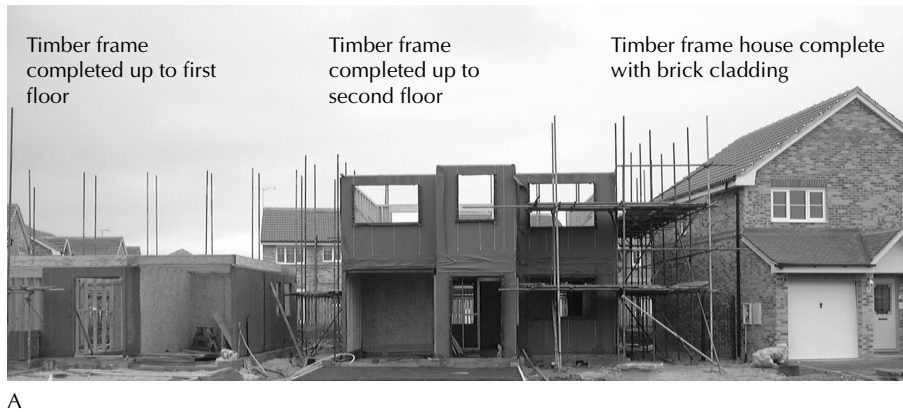
Photograph 1.1   Timber framed construction (courtesy of D. Johnston).

time' and the specification of the correct tolerances to allow operations to be conducted safely.

Tolerances

In order to be able to place individual parts in juxtaposition with other parts of the assembly a certain amount of dimensional tolerance is required. Construction involves the use of labour, either remote from the site in a factory or workshop, or on site, but always in combination. Designers must consider all those who are expected to assemble the various parts physically into a whole, including those responsible for servicing and replacing parts in the future, so that workers can carry out their tasks safely and comfortably.

   With traditional construction the craftsmen would deal with tolerances as part of their craft, applying their knowledge and skill to trim, cut, fit and adjust

materials on site to create the desired effect. In contrast, where materials are manufactured under carefully controlled conditions in a factory, or workshop, and brought to site for assembly, the manufacturer, designer and contractor must be confident that the component parts will fit together since there is no scope to make adjustments to the manufactured components. Provision for variation in materials, manufacturing and positioning is achieved by specifying allowable tolerances. Too small a tolerance and it may be impossible to move components into position on site resulting in some form of damage; too large a tolerance will necessitate a degree of 'bodging' on site to fill the gap – for practical and economic reasons both situations must be avoided. There are three interrelated tolerances that the designer must specify, which are related specifically to the choice of material(s).

(1) **Manufacturing tolerances**   Manufacturing tolerances limit the dimensional deviation in the manufacture of components. They may be set by a standard (e.g. ISO), by a manufacturer, and/or the design team. Some manufacturers are able to manufacture to tighter tolerances than those defined in the current standards. Some designers may require a greater degree of tolerance than that normally supplied, for which there may well be a cost to cover additional tooling and quality control in the factory.
(2) **Positional tolerances**   Minimum and maximum allowable tolerances are essential for convenience and safety of assembly. However, whether the tolerances are met on site will depend upon the skills of those doing the setting out, the technology employed to erect and position components and the quality of the supervision.
(3) **Joint tolerances**   Joint tolerances will be determined by a combination of the performance requirements of the joint solution and the aesthetic requirements of the designer. Functional requirements will be determined through the materials and technologies employed (see below). Aesthetic requirements will be determined by building traditions, architectural fashion and the designer's own idiosyncrasies.

As a general rule the smaller (or closer) the tolerance, the greater the manufacturing costs and the greater the time for assembly and associated costs. Help in determining the most suitable degree of tolerance can be found in the technical literature provided by trade associations and manufacturers. Once the tolerances are known and understood in relation to the overall building design it is possible to compose the drawings and details that show the building assembly. Dimensional coordination is important to ensure that the multitude of components fit together correctly, thus ensuring smooth operations on site and the avoidance of unnecessary waste through unnecessary cutting. A modular approach may be useful, although this may not necessarily accord with a more organic design approach.

Alternative approaches

There are a wide variety of approaches to the construction of buildings and with increased attention focused on ecologically friendly construction a number of different approaches are possible. Some have their roots in vernacular architecture and others in technological advancement, although most approaches combine features present in both old and new construction techniques. Strategies adopted can include, for example, the re-use of salvaged and recycled materials from redundant buildings, designing buildings that may be disassembled with minimal damage to the components used, buildings that are designed to decompose after a predetermined time frame, incorporation of renewal energy sources, etc. Care is required as many of these methods are largely untried (or the techniques have been forgotten) and it will take some time before we can really know for certain how they perform insitu. We do, however, urge all readers to consider the impact on the environment of their preferred construction method by adopting a whole life approach to the design, construction and use of buildings. With space in this book at a premium we can only highlight a few examples, but urge readers to investigate the issues for themselves before making a decision as to what construction method(s) to employ.

1.3 Regulations and approvals

Regardless of the approach adopted, a number of approvals need to be in place before building work commences. The two main consents required are from the appropriate planning authority and building control, both of which will be determined by the location of the construction site.

Planning consent

Issues concerning local town planning approval are outside the scope of this book, however it is important to recognise that (with a few exceptions) planning approval must be applied for and have been granted before any construction work commences. The legislation concerning the right to develop, alter and/or demolish buildings is extensive and professional advice should be sought before submitting for the appropriate approvals. The process of obtaining approval can be very time consuming (preparing the necessary information for submission, allowing time for consultation and decisions, etc.) and conditions attached to the approval may affect the construction process (e.g. restricted times of working, conditions on materials to be used, etc.). Sometimes the application may be unsuccessful, leading to an appeal or a submission of a revised proposal. Planning consent will permit development, it does not deal with how the building is to be constructed safely; this is dealt with by building control.

Building control and building regulations

During the last 50 years there has been a considerable increase in building control legislation, which initially was the province of local authorities through building bylaws and later replaced by national building regulations. In the UK building control is governed by three differing, though broadly similar sets of legislation, for England and Wales, Northern Ireland and Scotland respectively. Building regulations aim to ensure the health and safety of people in and around buildings by setting functional requirements for the design and construction of buildings. The regulations also aim to promote energy efficiency of buildings and contribute to the needs of people with disabilities, and in the case of the Scottish legislation promote sustainable development.

In England and Wales the Building Act 1984 and Building Regulations (1985) set out functional requirements for buildings and health and safety requirements that may be met through the practical guidance given in the Approved Documents; these in turn refer to British Standards and Codes of Practice. In Northern Ireland construction is covered by the Building Regulations (Northern Ireland) 2000 with Approved Documents, similar to those for England and Wales.

In Scotland the Building (Scotland) Act 2003 has replaced the old prescriptive standards with performance standards. The Act is a response to European harmonisation of standards and their use in Scotland as required under the Construction Products Directive (CPD). The Act has two objectives: to allow greater flexibility for designers in meeting minimum standards; and to ensure greater consistency across the country. There are separate Guidance Documents for domestic and non-domestic buildings, both of which are divided into six subject areas that match the essential requirements of the Construction Products Directive, namely: Structure, Fire, Environment, Safety, Noise and Energy.

The Approved/Guidance Documents give practical guidance to meeting the requirements, but there is no obligation to adopt any particular solution in the documents if the stated functional requirements can be met in some other way. The stated aim of the current regulations is to allow freedom of choice of building form and construction so long as the stated (minimum) requirements are satisfied. In practice the likelihood is that the majority of designers will accept the guidance given in the Approved/Guidance Documents as if the guidance were prescriptive. This is the easier and quicker approach to construction, rather than proposing some other form of construction that would involve calculation and reference to a bewildering array of British Standards, Codes and Agrément Certificates.

Although the guidance in this book is meant to be as broad as possible, when we make specific reference to regulations we have, both for consistency and to avoid confusion, worked to the Approved Documents for England and Wales. However, the principles for readers in Northern Ireland and Scotland are broadly similar, differences in detailing buildings arising from a combination

of legislation, response to local climate and building tradition. Full details of the Acts as well as the Approved Documents and Guidance Documents are available online (see Appendices).

Robust details

One of the latest developments linked to the Approved Documents (for England and Wales) is the publication of 'Robust Details'. The aim of the Robust Details is to assist the construction industry in achieving the performance standards published in Approved Document L1, by specifying performance standards and providing details (drawings) that show the intersection of various components. The details are intended to reduce risks and problems that can arise as a result of building to higher energy efficiency standards and, in the spirit of the Approved Documents, are intended as guidance. The Robust Details aim to reduce risk and uncertainty relating to:

❑ Interstitial condensation, which can deteriorate the structure
❑ Surface condensation, which can lead to mould growth
❑ Blockage of essential ventilation paths, which can lead to condensation building up
❑ Risk of rain penetration
❑ Higher heat loss than assumed/calculated
❑ Higher air leakage than assumed/calculated

The details have been prepared by the Department of Transport, Local Government and the Regions (DTLR) with support from the Department for Environment, Food and Rural Affairs (DEFRA). Current regulations and consultation papers are available from the office of the Deputy Prime Minister (see Appendices).

Associated legislation

In addition to the legislation set down in the Building Regulations, other legislation affects the way in which buildings are designed and built. For example, health and safety and fire safety legislation is covered in a number of documents that sit alongside the Approved/Guidance Documents. The European Union Council Directive 89/106/EEC (1988), the Construction Products Directive (CPD), requires all construction products to satisfy the Essential Requirements, which deal with health and safety issues, namely: Mechanical resistance and stability, Safety in case of fire, Hygiene, health and environment, Safety in use, Protection against noise, and Energy economy and heat retention. Over 600 CEN standards have been mandated under the CPD.

1.4 Making choices and sources of information

The design and construction of buildings is concerned with making choices. Decisions have to be made about the design of the building and its details,

which necessitates the selection of materials and components to realise the design intention and aspirations of the client. At the construction stage decisions have to be made about what mechanical plant to use, how best to sequence the work so that operations are conducted safely and efficiently and what to do when an unexpected problem occurs. The contents of this book are designed to assist with that decision-making exercise.

Readers should also make use of the information and details provided by manufacturers, but should avoid making a choice based on information from one source. Explore at least three different suppliers to compare functional and performance requirements, including costs and availability – then compare this with current legislation and standards – thus making a decision based on achieving the best value within given parameters.

Sources of information

Construction is essentially a process of assembly, where products are chosen from manufacturers' catalogues and/or from the builders' merchants and put together using a raft of different fixing techniques. Each new project brings with it a new set of challenges and a fresh search for information to answer specific problems. Some of the main sources of information for readers working in Britain are:

- ❑ Building Regulations and Codes
- ❑ British (BS), European (CEN) and International (ISO) standards
- ❑ British Board of Agrément (BBA)
- ❑ Building Research Establishment (BRE) publications
- ❑ Trade associations' technical literature
- ❑ Manufacturers' technical literature
- ❑ Technical reports in journals and the trade press

A note of caution

Finally, we must end this introductory chapter with a note of caution. Before proceeding any further it is necessary to make an important observation about the contents of this book. The principles and details illustrated here are meant as a guide to the construction of buildings. The details should not be copied without thinking about what is really going on, how the building is to be assembled and whether or not the detail in question is entirely suitable for the task in hand. We make this point because approaches to detailing and to construction vary from region to region (e.g. a building located in a wet and sheltered area of the UK may benefit from a pitched roof with a large overhang, but a similar building in a dry and exposed part of the country may benefit from a pitched roof with clipped eaves or even a flat roof). Building practices also differ from country to country (for example England and Denmark) and so it is impossible to cover every eventuality for every reader. Instead we

would urge readers to engage in some critical thinking, analyse the details and seek out alternative approaches where necessary. Buildings exist within a local context and they should be detailed to be in harmony with nature. The other point we must make is that regulations and building practices will change over time, therefore this book should carry a 'best before date'; as the regulations change some of the details will need to be revised. On a more positive note, the details will be a useful source of reference for readers involved in refurbishment and conservation projects at a future date. Our advice is to work closely with consultants, manufacturers and suppliers with the aim of applying their specialist knowledge to the benefit of the construction process, thinking critically and making informed decisions.

Further reading

Bett, G., Hoehnke, F. and Robinson, J. (2003) *The Scottish Building Regulations Explained and Illustrated* (*Third edition*), Blackwell Publishing, Oxford.

Billington, M.J., Simons, M.W. and Waters, J.R. (2003) *The Building Regulations Explained and Illustrated* (*Twelfth edition*), Blackwell Publishing, Oxford.

Emmitt, S. (2002) *Architectural Technology*, Blackwell Science, Oxford.

Emmitt, S., Olie, J. and Schmid, P. (2004) *Principles of Architectural Detailing*, Blackwell Publishing, Oxford.

2 Site Analysis and Set-up

The physical characteristics of the site and its immediate environment will influence the decisions to be made about a building's design and construction. The information gathered from a thorough site analysis is, therefore, a vital exercise and must be completed before any construction work commences. This information can then be collated in a performance appraisal document from which informed decisions about the best way to proceed may be made.

2.1 Function of the site analysis

Prior to any construction operations, the client/developer will want to know whether it is economically viable to build on the proposed site. As the nature and condition of the ground and soil below the site are an unknown quantity they pose a considerable risk to the construction project, with the potential to cause delays and additional costs, both of which can be substantial. Inadequate soil investigation and hence inappropriate foundation design can lead to structural problems at a later date, which is a problem for the building owners and users as well as the building insurers. Many projects are built on brownfield sites (land that has been previously built on and used) and it may be necessary to seal, stabilise or remove any contaminated ground, toxic waste or other dangerous substances before commencing the main construction works. The extent of contamination must be established before any work commences on the site.

The main purpose of site analysis is to identify and hence reduce the risks associated with the development by recording site features and soil characteristics, helping to determine the design and cost of suitable foundations and structure. A thorough site analysis is an essential first step that will assist development, design and construction decisions. The site analysis helps:

❑ The client to assess whether the project is viable
❑ The client, designer, structural engineer and contractor to locate the best position for the building, avoiding identified problems where possible and making the best possible use of physical features and environmental conditions
❑ The engineers to design the most suitable foundation system
❑ The mechanical and electrical consultants to design the service provision
❑ The designers and contractor to ensure that safe construction methods are used
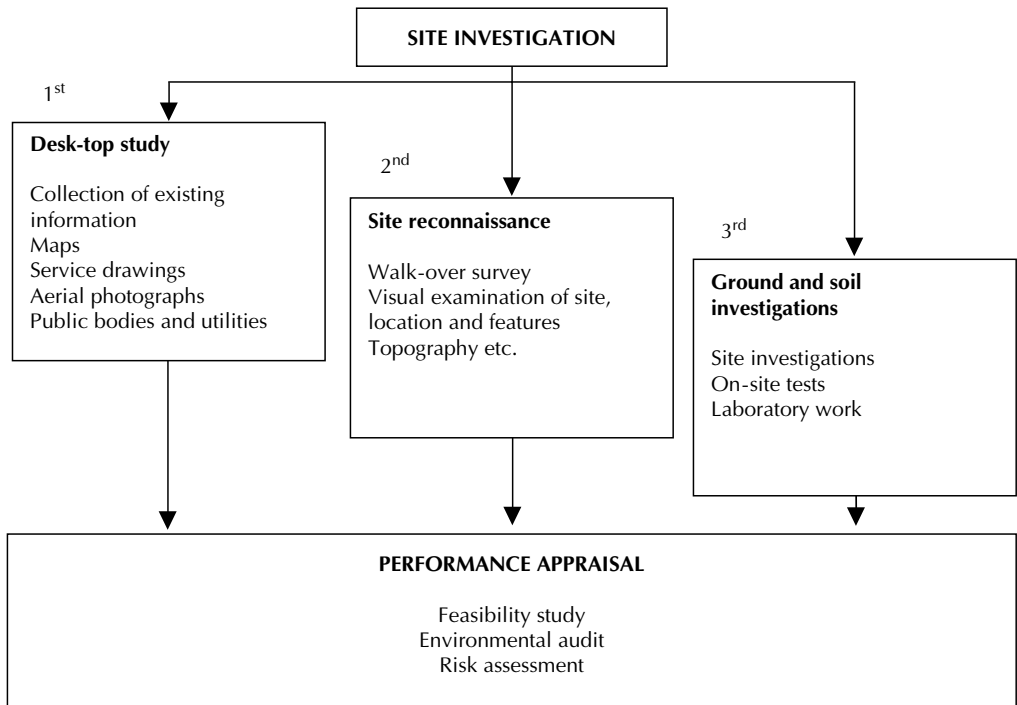
Figure 2.1   Sequence of site analysis.

❑ The environmental consultants to identify the most suitable way of dealing with any contaminants and problem materials, e.g. remediation works, material re-use, on-site treatment and disposal options.

Sequence of activities

The site analysis comprises three inter-related research activities; the desk-top study, the site reconnaissance and the ground and soil investigations. The soil investigation may also involve laboratory tests on liquids and gases found in soil samples. The order in which these activities are carried out will depend to a large extent on the nature of the development and the timescales involved. However, the preferred sequence of overlapping activities is shown in Figure 2.1.

2.2 The 'desk-top' study

The 'desk-top study' is a vital element in any site analysis exercise. The study involves the collection of all documents and materials that can be obtained

without having to visit the site. There is a considerable amount of information available from local and national authorities, museums, private companies and research groups. The client or previous owners may also have relevant information to hand.

Although the different site investigation operations often overlap, care should be taken not to commence with expensive ground exploration and soil tests before the desk-top study is completed. This is partly to avoid unnecessary work and expenses – for example, information from the desk-top study may reveal that recent site and soil investigations are available – and partly a health and safety issue since the approximate location of services and potential hazards must be known before carrying out any physical investigations. Early and thorough investigation of the available information may also show that the site is unsuitable for development or that special measures are required before proceeding further.

Information required

Ownership(s) and legal boundaries
The client should provide, via a legal representative, information pertaining to the exact location of the site boundaries and responsibilities for maintaining the boundaries. These will need to be checked against a measured survey and any areas of uncertainty checked by the legal representative. Other issues to be determined by the client's legal representative include:

- ❑ Rights of way
- ❑ Rights of light
- ❑ Rights of support (for adjoining properties)
- ❑ Legal easements
- ❑ Ownership of land (essential where parcels of land are being assembled to make a larger site)
- ❑ Rights of tenants, etc.

Ground conditions
As a first step it is usual to collect information on soil and subsoil conditions from the county and local authority, whose local knowledge from maps, geological surveys, aerial photography and works for buildings and services adjacent to the site may in itself give an adequate guide to subsoil conditions. In addition geological maps from the British Geological Survey, information from local geological societies, Ordnance Survey maps, mining, river and coastal information may be useful.

Services
All suppliers of services should be contacted to confirm the position of pipes and cables and the nature of the existing supply.

Contaminated land and methane

Previous use of land can give some clues as to the likely contaminants to be found and the local authority may have records that can help. However, extensive soil testing should be carried out to ascertain the nature and extent of any contamination. (See also Chapter 3.) Methane is associated with landfill sites, and local knowledge of old tips can prove useful at an early stage.

Radon

In certain areas of the UK, radon gas occurs naturally within the underlying ground and poses a threat to the inhabitants of buildings. Local authorities provide advice on the likely level of contamination and will advise on the extent of protection required to prevent the radon from entering the building.

Mining activity

The UK has a long and varied history of mining. Coalmining is the most common; however, certain geographical areas may have specific mining issues, for example salt mining in areas of Cheshire and tin mining in Cornwall. The position of mines and mine shafts, and their size, depth and condition may affect the positioning of buildings on a site and work to make old workings safe may add significant costs to the development proposal.

Flooding

Flooding of buildings and the subsequent damage to property and possessions and the associated disruption to businesses and family life has become a serious concern in recent years, as the frequency of flooding has increased. Factors include heavy rainfall, buildings sited on flood plains and inadequate maintenance of rivers and watercourses. Thorough checks should be made about previous flooding of the proposed site (if any) and any special requirements suggested or required by the various authorities.

Typical sources of information

Information will always be site-specific; however, the following list of information sources serves as a general guide:

❑ Ordnance Survey – detailed maps in many different formats are available from Ordnance Survey customer information, Romsey Road, Southampton S016 4GU (www.ordnancesurvey.co.uk)
❑ Historical maps (www.old-maps.co.uk) – local libraries
❑ Geological maps – the British Geological Survey is the national repository for geosciences data in the UK. Information provided includes maps, records and materials, including borehole cores and specimens from across the UK. Address: London Information Office, British Geological Survey,

Earth Galleries, Natural History Museum, Exhibition Road, London SW7 2DE (www.bgs.ac.uk)

❑ Hydro geological maps – soil reports and publication lists are obtainable from soil survey and Land Research Centre, Cranfield University, Silsoe, Bedford MK 45 4DT

❑ Meteorological information – monthly and annual reports are available on air temperature, wind speed, rainfall and sunshine. Such information is useful for construction and potential use of the building. Statistics on averages and extremes for various elements are also available. The Met Office, Room JG6, Johnson House, London Road, Bracknell, Berks RG12 2SY (www.metoffice.gov.uk)

❑ Hydrological information – surface water run-off data are collected by water authorities, private water undertakings and local authorities

❑ Site history:
  ○ previous owners and developers
  ○ site surveys and drawings used for previous development
  ○ records held by Building Control
  ○ local newspaper archives
  ○ records held by the local planning authority

❑ Gas supplier – location of gas mains

❑ Electricity supplier – location of electricity cables

❑ Electricity generating board – mains electricity cables

❑ Water suppliers – water supply mains

❑ Mains sewers

❑ Local authority – local sewers

❑ Telecommunications authority – telephone and optical cables

❑ Rail authority – railways

❑ British Water Board – canals

❑ British coal – underground working building inspector

❑ Aerial photographs – there are many collections of aerial photographs dating back over many decades. A directory of organisations and agencies that hold aerial photographs can be obtained from Publications Department, Aslib, The Association for Information Management, Information House, 20–24 Old Street, London EC1V 9AP

2.3 Site reconnaissance

Written permission should be acquired from the client and/or owners before entering the site and especially before any invasive investigations are carried out (which may require separate written permission). Obvious considerations are related to trespass and criminal damage, although the prime concern must be the safety of those doing the investigations. The majority of sites will have been used previously (and may still be in use) and may contain buildings that may be structurally unsound (which may be redundant or still in use despite

their condition). Thus approvals must be in place and a thorough risk assessment exercise must be carried out before entering the site. Where buildings exist, specialists should be used to establish the condition and safety of the structure and whether asbestos is present.

The visual inspection of the site

A visit to the site and its surroundings should always be made to record everything relevant to the proposed development. The site reconnaissance is often referred to as the visual inspection or the 'walk over'. From experience we have found that two pairs of eyes (or more) are always better than one and so the visual inspection should be undertaken by at least two, and preferably three, people, e.g. the architect, engineer and contractor, with each taking their own notes but discussing features as they come across them. Careful observation should be made of the nature of the subsoil, vegetation, evidence of marshy ground, signs of ground water and flooding, irregularities in topography, ground erosion and ditches and flat ground near streams and rivers where there may be soft alluvial soil. A record should be made of the foundations of old buildings on the site. Cracks and other signs of movement in adjacent buildings should be noted. When undertaking site reconnaissance on contaminated land, ensure as far as possible that all hazards have been identified and that correct safety procedures are followed. In preparation for the site reconnaissance, all of the maps and records should assembled so that any differences or omissions found when walking over and observing the site can be recorded. A visual inspection of physical site boundaries should be made and compared with any legal documents that show boundaries.

British Standard procedure for walk-over surveys

When conducting a walkover survey, the British Standard for site investigations (BS 5930:1999) suggests that the surveyor should:

- ❏ Traverse the whole area on foot, if possible
- ❏ Establish the proposed location of work on plans
- ❏ Identify and record any differences on the plans and maps
- ❏ Record details of existing services, trees, structures, buildings and obstructions
- ❏ Check access and determine capability of sustaining heavy construction traffic
- ❏ Record water levels, fluctuations in levels, direction of flow and flow rate
- ❏ Identify adjacent property and the likelihood of it being affected by proposed works
- ❏ Identify any previous or current activities that may have led to contamination
- ❏ Record mine or quarry workings, old structures and other features

❑ Record obvious features that pose immediate hazard to public health and safety or the environment
❑ Record any areas of discoloured soil, evidence of gas production or underground combustion

During a site reconnaissance the following ground information and features should be noted (BS 5930:1999):

❑ Record surface features on site and on adjacent land, note the following:
  ○ Type and variability of surface conditions
  ○ Compare land and topography with previous records, check for fill, erosions and cuttings
  ○ Any steps in the surface that may indicate geological faults. Steps in mining areas may be the result of subsidence. Other evidence of subsidence caused by mining may include compression or tensile damage to structures and roads, structures out of plumb, interference with the line of drainage patterns
  ○ Mounds and hummocks in relatively flat country often indicate former glacial conditions, e.g. glacial gravel
  ○ Where the ground is terraced and broken on hill slopes this may be due to landslips; small steps and inclined tree trunks may be evidence of creep and ground movement
  ○ Crater type holes in chalk or limestone usually indicate swallow holes that have been filled with a soft material
  ○ Low-lying flat areas in hill country may be the site of a previous lake and can indicate the presence of soft silts and peat
❑ Record details of ground conditions in quarries and cuttings
❑ Record ground water levels (these are often different from streams, ponds and lakes)
❑ Identify the position of wells and springs
❑ Note the nature of vegetation in relation to soil type and wetness of soil. Unusual green patches, reeds, rushes, willow trees and poplars usually indicate wet ground conditions
❑ Investigate structures in the vicinity of areas having a settlement history

Identification and physical location of services

Before undertaking any digging, e.g. for trail holes, it is necessary to clearly identify the nature of the services on the site and their actual position. Unfortunately, the majority of the plans provided by the services providers only give an approximate location of their pipes and cables, therefore some detective work is required on site. The first task is to identify all inspection covers and the nature of the service, and compare their positions with those on the drawings. Handheld sonic and magnetic detecting devices are available from

most plant hire firms for locating positions of services. Further information on depth and exact position can be found by exposing the services by carefully hand digging trial pits. The service providers will also be keen to establish exact positions in an attempt to prevent damage to their pipes and cables. The organisations responsible for particular services should be invited to the site to help to establish the exact position, size and capacity of their supply and to resolve any uncertainty.

In order to develop the site to its full potential services may need to be re-routed, if the appropriate authority will allow this. Re-routeing services is often expensive and may threaten the viability of the project. Alternatively, the proposed position of the building on the site may need to be adjusted to enable the project to proceed without undue disruption to major service routes.

Surveys

Photographic and video survey
Photographic and video surveys are useful tools to prompt one's memory when back in the office and also as a record of the original condition of the site and adjoining land/property in case of any dispute. Photographic surveys should be conducted in a systematic and thorough manner, with the position of the photographer and direction of view noted on a site plan to avoid any future confusion.

Measured survey
A land surveyor should conduct a topographical survey to establish the physical boundaries, existing features and variations in level. Most land surveyors have a standard list of features to be established during the land survey, although it is not uncommon to direct the land surveyors to particular areas to record additional information.

Condition survey
Condition surveys are used to record the condition of boundaries and adjoining property prior to work commencing. Condition surveys are also employed to record the state of existing buildings on the site that are to be protected, refurbished or altered. Detailed drawings and written descriptions of the property are supported with photographic evidence. These form the basis for additional work and a record in the event of any future dispute.

Survey of adjoining properties
Before commencing any work that is likely to result in vibration (e.g. demolition, excavations, piling, heavy construction traffic, etc.) it is important to undertake a full condition survey of surrounding and adjoining properties and structures. This serves as a record for any subsequent claims for damage and also serves as a good source of design information, for example, indicating how particular materials have weathered.
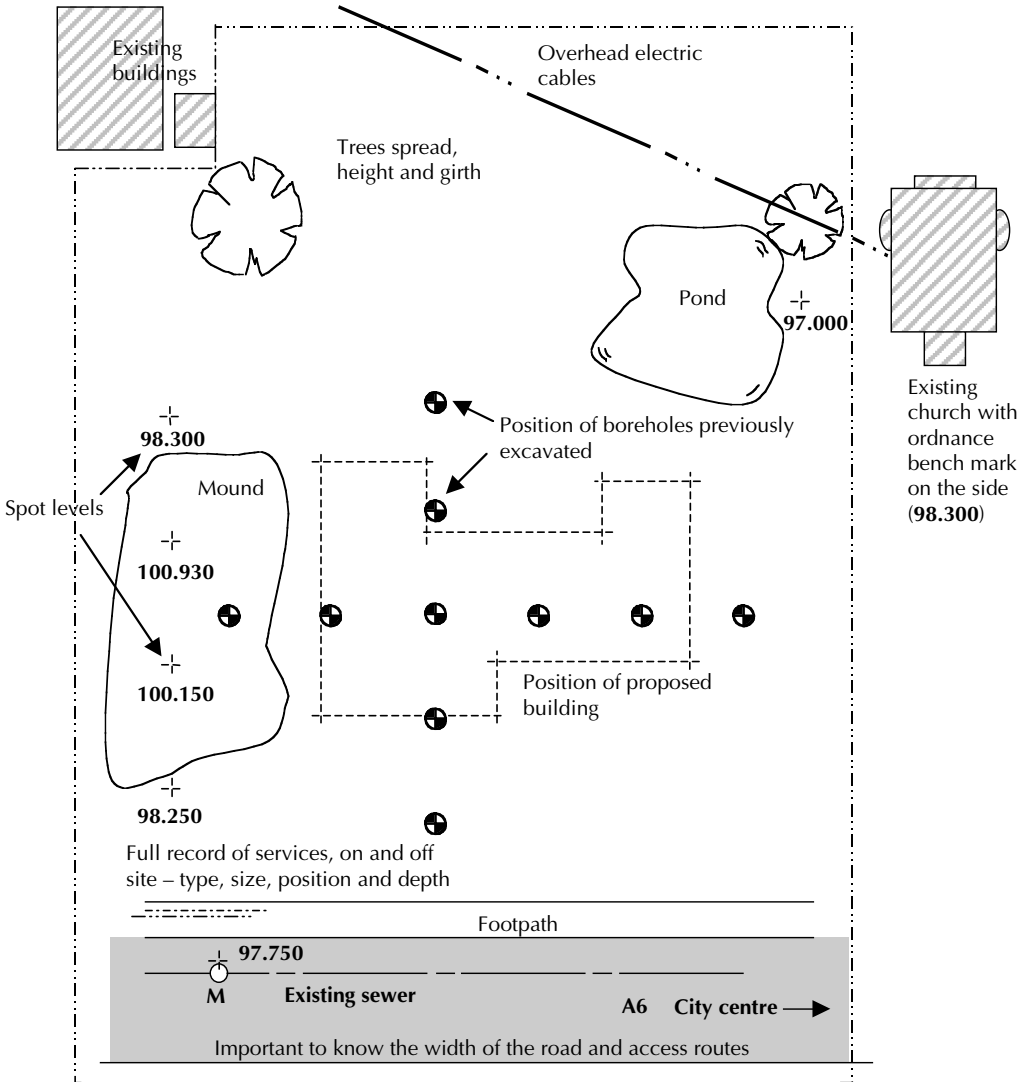
Figure 2.2   Schematic showing information collected during site reconnaissance.

Site reconnaissance: typical information collected
The schematic in Figure 2.2 provides an overview of information that can be collected during site reconnaissance.

2.4 Soil investigations

Details of the subsoil should include soil type, consistency or strength, soil structure, moisture conditions and the presence of roots at all depths. From

the nature of the subsoil the bearing capacity, seasonal volume changes and other possible ground movements are assumed. To determine the nature of the subsoil below foundation level it is necessary either to excavate trial pits some depth below the assumed foundation level or to bore in the base of the trial hole to withdraw samples. When proposing work to existing buildings (for example, adding another floor) it will be necessary to expose the existing foundation in a number of places to check if it was built as detailed on drawings (if available) and also to check the subsoil below the foundation. Whichever system is adopted will depend on economy, the proposed building works and the nature of the subsoil. Trial pits or boreholes should be sufficient in number to determine the nature of the subsoil over and around the site of the building and should be at most, say, 30 m apart.

Ground movements that may cause settlement are:

❑ Compression of the soil by the load of the building
❑ Seasonal volume changes in the soil
❑ Mass movement in unstable areas such as made up ground and mining areas where there may be considerable settlement
❑ Ground made unstable by adjacent excavations or by de-watering, for example, due to an adjacent road cutting.

Foundation design and subsoil examination

To select a foundation from tables, or to design a foundation, it is necessary to calculate the loads on the foundation and determine the nature of the subsoil, its bearing capacity, likely behaviour under seasonal and ground water level changes and the possibility of ground movement. Where the nature of the subsoil is known from geological surveys, adjacent building work, trial pits or borings and the loads on foundations are small, as for single domestic buildings, it is generally sufficient to excavate for foundations and confirm, from the exposed subsoil in the trenches, that the ground is as anticipated. Table 2.1, provides a guide on the allowable bearing pressure of different classifications of ground.

Where loads may be more substantial or there is little evidence available on the nature of the ground, boreholes and trial pits will need to be excavated. The depth of exploration will be related to the proposed foundation and loads imposed on the subsoil.

Under pad foundations there is a significant pressure on the subsoil to a depth and breadth of about one-and-a-half-times the width of the foundation; the depth of pressure is slightly greater for strip foundations (Table 2.2, Figure 2.4). If, at any point where the foundation exerts this bulb of pressure, the soil bearing capacity is less than the load exerted by the foundation, then appreciable settlement of the foundation can occur and damage the building (Figure 2.3). It is important, therefore, to know or ascertain the nature of the

Table 2.1   Allowable bearing pressure of soil and ground

Soil and ground classification	Bearing capacity (kN/m^2)
Rocks	
Strong sandstone	4000
Schists	3000
Strong shale	2000
Granular soils	
Dense sand and gravel	>600
Medium dense gravel	200–600
Loose sand and gravel	<200
Compact sand	>300
Loose sand	<100
Cohesive soils	
Stiff boulder clay	300–600
Stiff clay	150–300
Firm clay	75–150
Soft clay and silt	<75

Adapted from BS 8004,1986

Table 2.2   Depth of effective bulb pressure

Foundation type	Effective bulb pressure
Strip	3 × the width of foundation
Pad	1.5 × the width of foundation
Raft	1.4 × the width of foundation

subsoil both at the level of the foundation and for some depth below. Figure 2.4 shows typical forces exerted on the sub-structure at a depth of one and a half times the width of the foundation. The loads placed on a pad foundation are generally distributed over a greater surface area, reducing the load per unit

If the pressure exerted by the foundation is greater than the bearing pressure of the soil then settlement will occur.

If it is predicted that the bulb of pressure will exert force on a weak stratum then a different foundation system will need to be used.

b

1.5 b   Good stratum
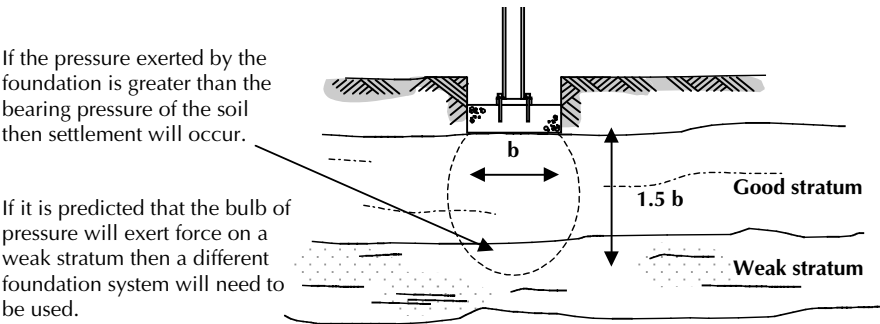
Weak stratum

Figure 2.3   Example of foundation exerting pressure on weak stratum: may lead to settlement.

pad foundation   strip foundation

Load per unit
area = q

b

1.5 b

0.2 q

Width of
foundation = b

b

0.38 q

A Pressure at this point is less than 0.2
of the load per unit area of the
foundation

B Pressure at this point is less than
0.38 of the load per unit area of the
foundation
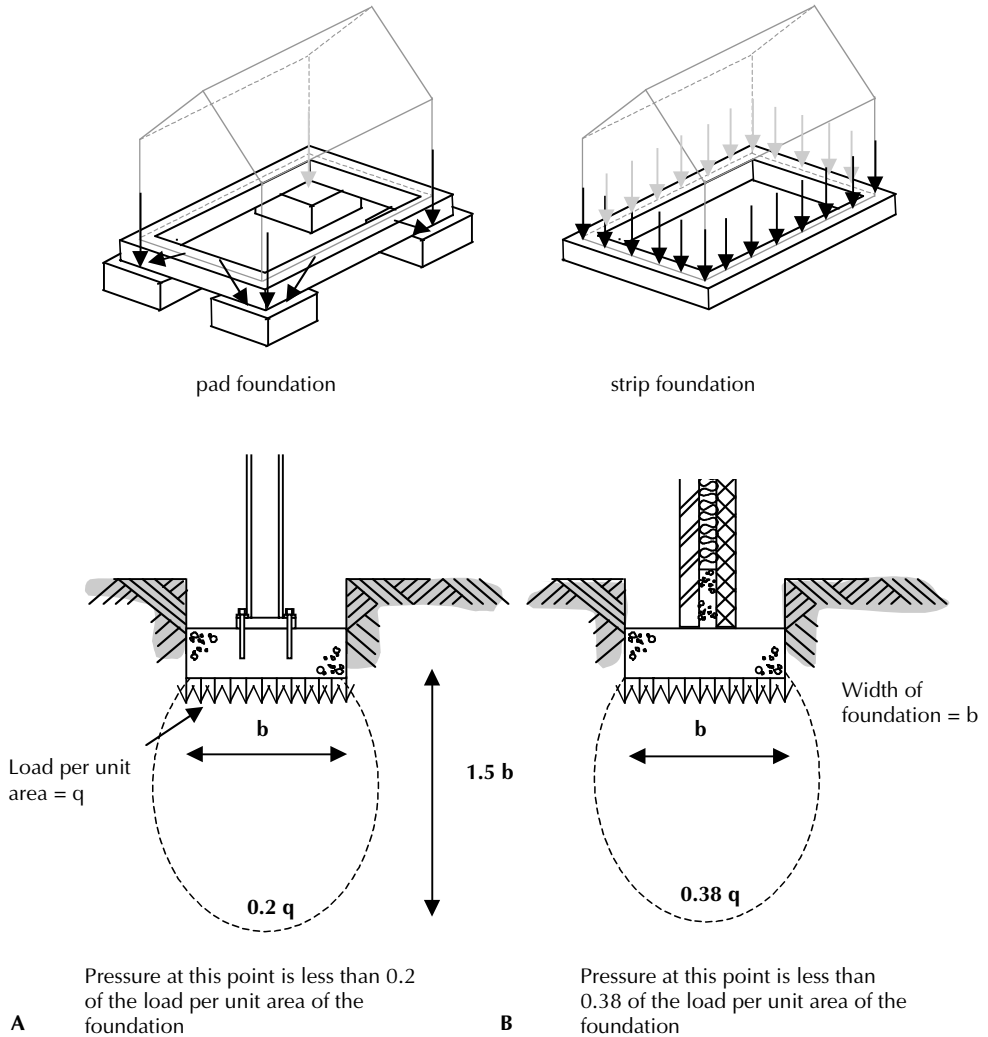
Figure 2.4   A & B Bulb of pressure exerted under a pad and strip foundation.

area. Strip foundations transfer the loads from the wall directly to the ground. Although strip foundations do spread the load over a slightly greater surface area they exert continual pressure along the ground (Figure 2.4).

Care should be taken where foundations are positioned close to each other, or a new foundation is placed next to an existing structure. Each foundation exerts a force on the ground that is distributed at an angle of approximately 45°. Where the pressure exerted on the ground by the foundations overlaps, the soil has to bear the force of both foundations (Figure 2.5). If the force exerted

Angle of maximum shear 45°

Where foundations are close together the stress exerted on the soil can overlap increasing the force in this area
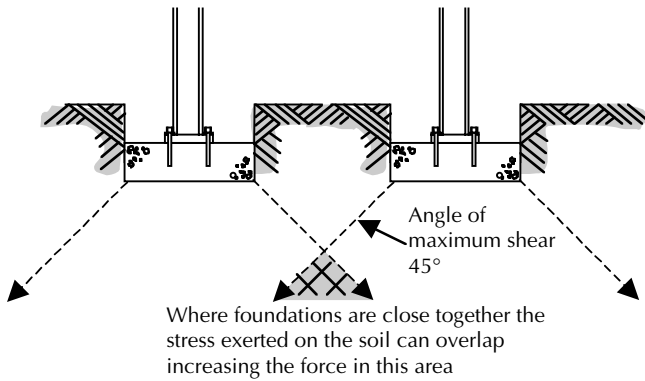
Figure 2.5 Combined stress exerted on subsoil from foundations in close proximity.

by both foundations is greater than the bearing capacity of the soil, the ground will fail and the foundation may settle.

Trial pits

To make an examination of the subsoil on a building site, trial pits or boreholes are excavated. Trial pits are usually excavated by a mechanical excavator, or in some cases by hand tools, to a depth of 3 to 4 m. The nature of the subsoil is determined by examination of the sides of the excavations. Soil and rocks can be examined insitu on the faces of the excavated pit, and samples taken for further laboratory tests. The trial pit also provides an indication of the ease of dig (or excavation), trench stability and groundwater conditions. For exploration of shallow depths (up to 3 m) this is usually more economical than boreholes. The pits are usually rectangular, being approximately 1.2 × 1.2 m in plan. The pits should be excavated in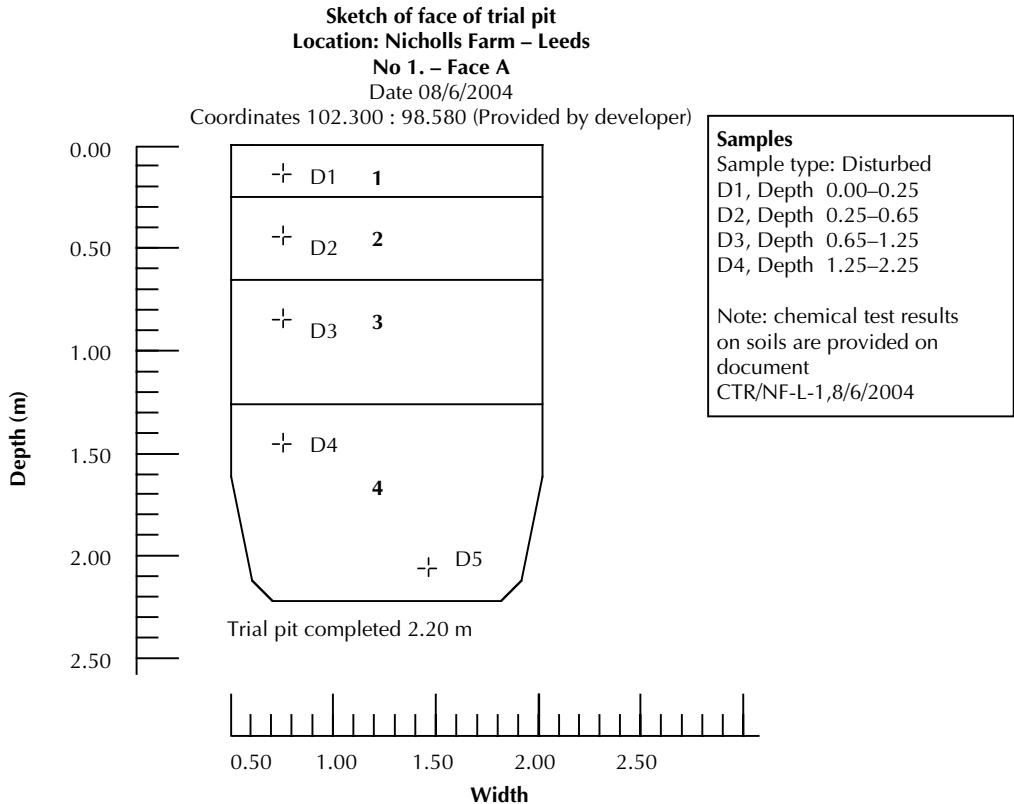 the vicinity of the proposed structure; if the pit is located under a proposed foundation particular attention needs to be given to the material used to backfill the hole. In such situations material should be of sufficient strength and well compacted.

When investigating the soil characteristics, details collected should include soil type, consistency or strength, soil structure, moisture conditions and the presence of roots at all depths. From the nature of the subsoil the bearing capacity, seasonal volume changes and other possible ground movements are assumed. To determine the nature of the subsoil below the foundation level it is necessary either to excavate trial pits some depth below the foundation or to bore in the base of the trial hole to withdraw samples. Trial pits or boreholes should be sufficient in number to determine the nature of the subsoil over and around the site of the building. As each trial pit is excavated and inspected a report should be made of the inspection. Typical information contained in the inspection, the trial pit log, is shown in Figure 2.6.

Sketch of face of trial pit
Location: Nicholls Farm – Leeds
No 1. – Face A
Date 08/6/2004
Coordinates 102.300 : 98.580 (Provided by developer)

Samples
Sample type: Disturbed
D1, Depth 0.00–0.25
D2, Depth 0.25–0.65
D3, Depth 0.65–1.25
D4, Depth 1.25–2.25

Note: chemical test results
on soils are provided on
document
CTR/NF-L-1,8/6/2004

D1 **1**
D2 **2**
D3 **3**
D4
4
D5

Trial pit completed 2.20 m

Depth (m): 0.00, 0.50, 1.00, 1.50, 2.00, 2.50

Width: 0.50 1.00 1.50 2.00 2.50

Strata
(1)   Topsoil and grass 220 mm
(2)   Made ground: firm to stiff orange brown sandy clay with a little gravel of limestone
(3)   Made ground: soft to firm dark grey clay with occasional rootlets
(4)   Medium dense dark grey clay

Notes:
(1)   Groundwater: no groundwater encountered
(2)   Variability of faces: all faces were similar
(3)   Stability of faces: all faces were stable
(4)   Weather: overcast

Figure 2.6   Trial pit log.

Boreholes

'Borehole' is often used as a generic term that represents the various methods used to excavate and extract disturbed and undisturbed soil samples. All samples taken from boreholes should be sealed as soon as possible to minimise

any loss of moisture before testing. Some of the most commonly used methods are.

Auger boring

These holes are usually made by hand or powered auger into the ground. Auger holes are typically 75–150 mm in diameter. Short helical augers are used and disturbed samples of soil are collected as they are brought to the surface. Such methods are not widely used as they do not allow the soil to be examined insitu and are not capable of penetrating to the depth of boreholes.

Window samplers

A window sampler is a steel tube about 1 m long with a hole cut into the wall of the tube allowing the disturbed sample to be viewed or soil samples taken from the tube. The tube is driven into the ground using a lightweight percussion hammer and extracted with the aid of jacks. A range of tube diameters are available. In practice the large tubes are driven in first and removed leaving a hole for smaller tubes to be inserted and driven in further. Samples can be obtained down to a depth of 8 m.

Percussion boring

Boreholes are normally made using light percussion equipment. The 150–200 mm diameter weighted hollow tube is dropped into the hole so that the soil becomes lodged within the tube. The tube is then lifted to the surface and the sample removed. In clay soils the method relies on the cohesive properties of the soil to hold it in the tube (claycutter). In granular soils a hollow tube with a flap over its base is used (shell or bailer). A single day's drilling can excavate up to 15 m (typically 7–15 m).

The materials that are collected during the drilling and excavation can be retained as disturbed samples; however, in cohesive soils a 100 mm diameter tube can be dropped to the bottom of the hole to collect an undisturbed sample (undisturbed sampling is generally confined to cohesive soils). The tube is then taken back to the laboratory for further tests. Standard penetration tests and vane tests can be carried out in the borehole as the drilling and excavation process proceeds.

Photographic evidence from boreholes

In very stiff clays and fissured rock it is possible to take photographs of the strata using a remote-controlled borehole camera. If is clear that a borehole has entered a void, photographic evidence may determine the nature of the void, e.g. mine shaft, sewer, cave, etc.

Depth and location of exploratory investigation

The information obtained from boreholes and trial pits will be used to design suitable foundation systems. Boreholes must penetrate through all unsuitable

Borehole

Depth of
foundation

Breadth of
foundation

Borehole depth = Depth of foundation + 1.5 ×
Breadth of foundation
BHD ≥ (D+1.5 × B)
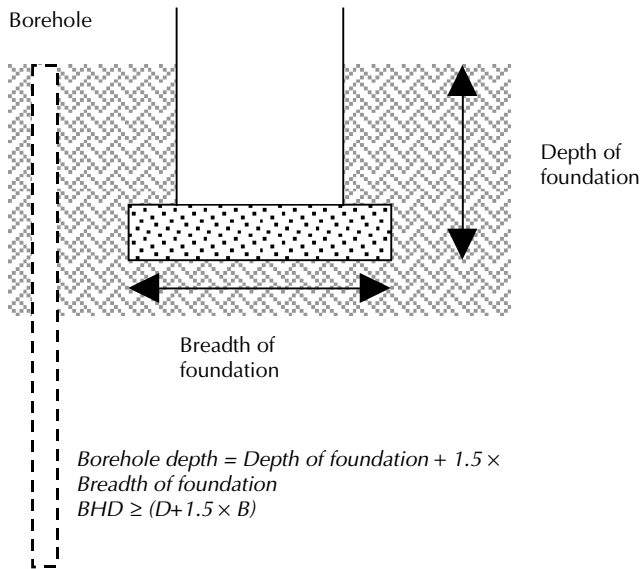
Figure 2.7   Depth of borehole for pad and raft foundations.

deposits such as unconsolidated fill, degradable material, peat, organic silts
and very soft compressible clay. Once a suitable bearing stratum is reached,
the depth of the borehole can be calculated. For low-rise buildings the
depth of the borehole can be calculated using the following formulae (BRE
1995).

Isolated pad or raft foundations
Where the structure rests on an isolated pad or raft foundation (Figure 2.7) the
following formula is used to calculate the depth of borehole required:

$$Borehole\ depth = Depth\ of\ foundation + 1.5 \times Breadth\ of\ foundation$$
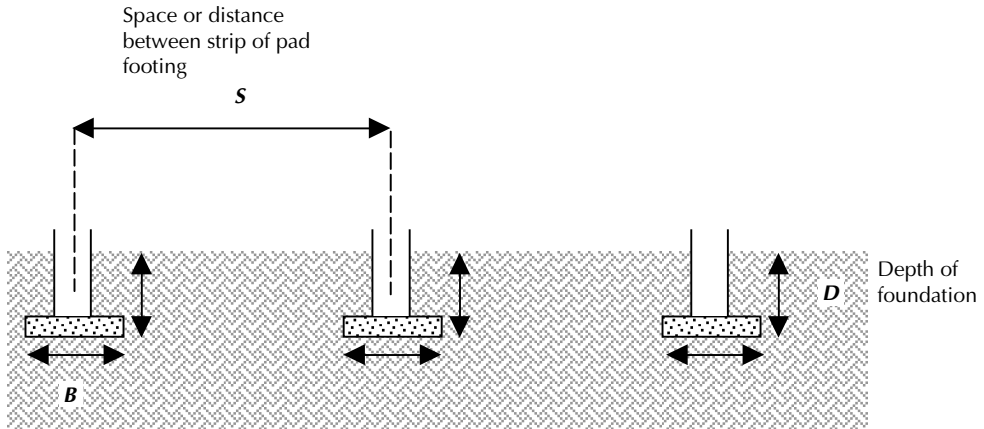
$$BHD \geq (D + 1.5 \times B)$$

Closely spaced strip or pad foundations
Where the structure rests on closely spaced strip or pad foundations (Figure 2.8)
the following formula is used to calculate the depth of borehole required:

$$Borehole\ depth = Depth\ of\ foundation + 1.5 \times (2 \times Space\ between\ foundations$$

$$+ Breadth\ of\ foundation)$$

$$BHD \geq D + 1.5(2S + B)$$

*Borehole depth = Depth of foundation + 1.5 × (2 × Space
between foundations + Breadth of foundation)*
BHD ≥ D+1.5(2S + B)
Used where S is less than 5 times B

Figure 2.8   Depth of borehole for closely spaced strip or pad foundation.

Borehole depth = Depth of pile foundation + 3 × breadth
BHD ≥ (D+3B)
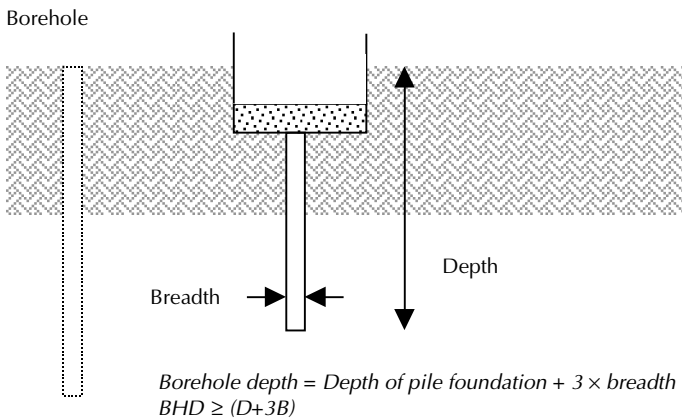
Figure 2.9   Depth of borehole for friction piles.

Structure on friction piles
Where friction piles are used (Figure 2.9), the calculation is:

$$Borehole\ depth = Depth\ of\ pile\ foundation + 3 \times Breadth$$

$$BHD \geq (D + 3B)$$

BRE (1995) procedure for site investigations in low-rise buildings suggests
that boreholes should be drilled in straight lines to facilitate section drawings
(Figure 2.10).

A Plan showing position of boreholes   **B**   Sectional drawing

Figure 2.10   A & B Plan and section showing the position of boreholes.

Ground and soil tests

There are a wide variety of on-site and laboratory tests that can be used to establish the characteristic ground and soil conditions. The extent of soil investigation will be based on the nature of the building and characterist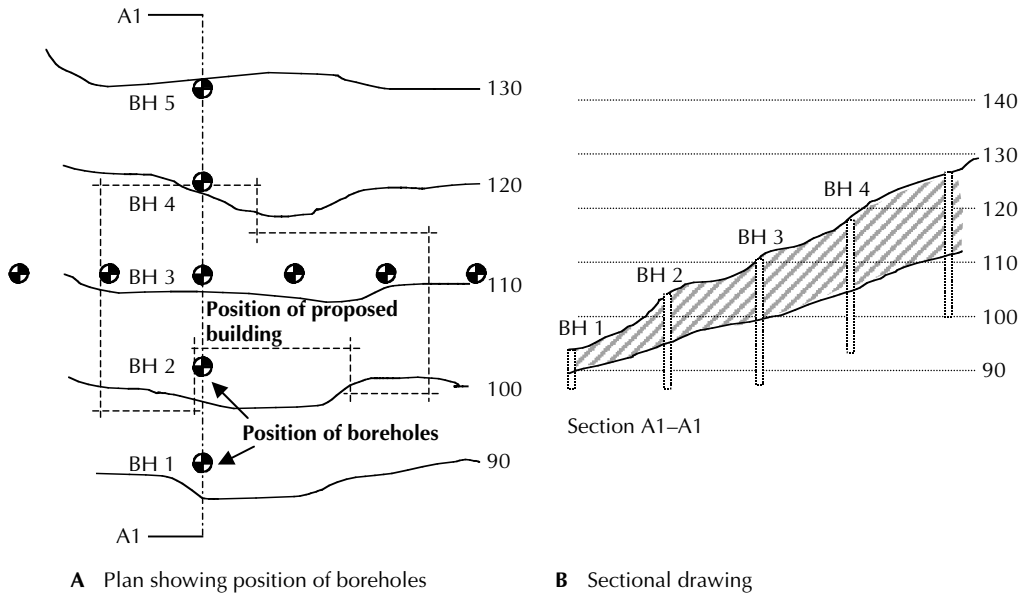ics of the site. More detailed site and laboratory studies will provide more information, reducing the risks inherent in building on unknown ground. Laboratory and on site tests that can be used include:

On-site test
- ❑ Plate load test
- ❑ Vane shear test
- ❑ California bearing ratio (CBR) test
- ❑ Dry density/moisture relationship
- ❑ Standard penetration tests (SPT)
- ❑ Lightweight dynamic penetometers
- ❑ Cone penetration tests (CPT)
- ❑ Methane/oxygen/carbon dioxide/barometric pressure test

Laboratory work
- ❑ Triaxial compression tests
- ❑ Liquid and plastic limit tests
- ❑ Sieve analysis – particle size and distribution

❑ Moisture content
❑ PH value tests

Further information on site and soil investigation is included in *Barry's Advanced Construction Technology*.

2.5 The performance appraisal

When the information has been collected from the desktop study, the site reconnaissance and the ground and soil investigations it must be brought together in the form of a final report, the performance appraisal.

Structure of the report

The main headings should address the following.

Feasibility study
Is the proposed development feasible? Are alterations required to improve constructability given that more information is available than at the start of the project? How does the information gathered affect the client requirements as stated in the development brief?

Environmental audit
Environmental impact assessments and environmental impact statements can be prepared and recommendations considered. How does this information affect the proposed development?

Risk assessment
Given that all building activity carries some degree of risk, it is important that risk assessments are carried out before proceeding further. Decisions can be made to eliminate, reduce or accept the risk associated with particular work packages.

Conclusions and recommendations
Clear and concise conclusions based on the information gathered need to be made and any areas requiring further detail/research clearly stated. All recommendations need to be related to the client brief and supported with accurate costing where possible, thus enabling informed decisions to be taken.

2.6 Site set-up and security

Site planning is important, especially for sites with limited space and/or those located in busy areas. Although this is usually covered under the literature on

construction management a brief summary of the main issues to be considered are presented here.

Site set-up

Access
Access to the site is required for personnel, construction plant and delivery vehicles during construction. Fire-fighting equipment must also have clear access in case of a fire or emergency occurring during the works. Temporary access may be allowed in consultation with the appropriate Highways, Police and Town Planning departments. Safe access for large cranes and wide, heavy and/or long loads will also need careful planning.

Storage and waste
Materials and plant must be stored so as to protect them from the weather and from damage from site operations. This applies equally to materials stored on site for a short period and those stored for a longer period. Space for the construction and subsequent protection from damage of sample panels is a related consideration. The reduction of waste on site is linked to good site management and to good detailing. When detailing a building, attention should be given to reducing the amount of cutting and hence waste generated on the site (which is expensive to dispose of).

Services and accommodation
As a minimum a suitable, metered supply of electricity and water will be required; so too will foul drainage. Site personnel require office space and comfort facilities. These are usually provided in specialist pre-fabricated site units that are hired by the contractor for the duration of the project. The wellbeing of construction workers and also visitors to the site is an important factor.

Security and safety

Site security is required for two reasons. First, to protect the materials and plant left on the site overnight from theft and malicious damage. Second, to stop members of the public from inadvertently wandering on to the site and hence endangering their safety; thus perimeter fencing must be secure and all access points monitored. In addition to fencing and physical barriers to unauthorised entry, many contractors also employ security firms to provide additional protection at night and at weekends. Monitoring of materials entering and leaving the site is also required to prevent pilfering by site workers.

Statutory requirements
All work must comply with the relevant Building Regulations, Town Planning consent (conditions may relate to the protection of trees and boundaries, archaeological digs, restricted working times, etc.) and other statutory

requirements relating to the construction works such as health and safety legislation. House builders may also need to consult the most recent edition of the *NHBC Standards*.

Levelling and setting out

Once all of the information on the site has been collected, appropriate levels and positions for the buildings must be established. To determine a level for the building it is necessary to find the levels and gradients of the land, the amount of material that will need to be removed, e.g. unstable or degradable material such as topsoil and waste. Once the lie of the land is mapped out then the loadbearing strata on which the floor construction and foundations can rest is determined. In most cases the ground floor level is positioned slightly higher than the existing ground level. By positioning the floor level above the external ground level unnecessarily deep excavation is avoided and problems of groundwater penetration are reduced.

Setting out for excavation and construction

As soon as the contractor has obtained legal possession of the site, and has made the site safe and secure, the land must be taken down to workable levels and buildings and grid lines should be set out. Before any work can commence a temporary benchmark should be established. The temporary benchmarks will provide a fixed known level on site. All other levels for footings, floor levels, road levels, etc. can be determined by working out the difference in levels from the temporary benchmark.

In order to establish the on-site temporary benchmark a fixed reference point off site needs to be found, i.e. Ordnance Survey record benchmarks that have been established on existing structures. Benchmarks can often be found on churches, bridges, and other large structures (and should be shown on the land surveyor's drawings). Once the level has been found it can be transferred to site. Site-based temporary benchmarks should be placed on a sturdy structure in positions where they are not liable to be knocked or disturbed. The benchmark should be recorded on a site plan for reference during construction.

Reference points on the ground also need to be determined to position the building and associated works correctly. North- and east-based coordinates are used to position grid lines; these may be obtained using a GPS (global positioning system) or using two reference points with known coordinates. Alternatively, the building or grid lines can be simply set out off existing structures.

Reduced level dig

Once a level has been established and gridlines or building lines marked out the reduce level dig can commence. Generally, areas of the site where major excavation will take place are reduced. Under buildings the reduced level dig

is excavated to the underside level of the floor construction; this is the largest volume of excavation that should take place. Reducing the level of the site where buildings are positioned helps to provide a level site for ease of work. Foundations that go deeper than the underside of the floor construction are excavated independently from this level.

Temporary weather protection

Materials delivered to site require temporary protection until they are placed in the correct position; so too does work as it proceeds, for example brickwork requires protection from the extremes of climate. Workers and building work will need to be protected from the vagaries of the weather. Getting the building weathertight as quickly as possible is a major help to protecting workers from wind and rain, although cold weather working needs particular attention.

Cold weather working

As a general rule, work should not proceed when the air temperature is below or likely to fall below 2°C. Frozen material must not be used. The temperature should be monitored and recorded at regular intervals. A maximum and minimum thermometer, sited in the shade, will indicate whether the temperature is falling or rising. Weather forecasting services, such as that provided by the Meteorological Office can help in planning work over a slightly longer period. Work must be planned and adjusted to mitigate the effects of cold weather. Special attention should be paid to wind chill and topographical features. Strong winds can reduce the temperature of mortar and concrete (and site personnel) more quickly than still conditions, therefore, the wind chill factor must be considered in the planning of work. Topographical features, such as hollows in the ground or sites over-shadowed by high trees or buildings will have their own micro-climate, often warming up slower than sites that benefit from the sun's rays.

Stored materials must be protected from cold weather. Covers can be placed over materials to protect them from frost, ice, rain and snow and should be in place at the end of each working day. Covers should also be used to protect newly laid masonry and concrete. During prolonged cold weather heaters may be used to protect materials from being frozen.

Concrete should not be placed in foundation trenches or oversite when the ground is frozen because movement will damage the work when the temperature rises and the ground thaws. All formwork, reinforcement and other surfaces that come into contact with fresh concrete must be free of frost, ice and snow. Ready-mixed concrete must be a minimum of 5°C when delivered (a requirement of BS 5328). Site-mixed concrete should not be used if the air temperature is below 2°C. However, if the aggregate temperature is above 2°C and free of frost and snow, and the water for mixing is heated (but not over 60°C), the cement is not heated, the ground is not frozen and the cast work can

be protected against frost, then work can proceed. At low temperatures curing times will be extended, depending on the severity of the conditions, by up to six days.

Masonry should not be laid when the temperature is below or is likely to fall below 2°C unless heating is provided and the materials have not been damaged by frost or are frozen. New masonry must be protected against frost damage with covers and heating in severe weather.

The use of admixtures should be used sparingly and always in accordance with the manufacturers' recommendations. Plasticisers provide improved frost resistance to mature mortar and concrete. Accelerators may help the mortar or concrete to set before the temperature falls.

Further reading

Fryer, B., Egbu, C., Ellis, R. and Gorse. C.A. (2004) *The Practice of Construction Management: People and Business Performance, 4th edn.*, Blackwell Publishing, Oxford.

3 Groundwork and Foundations

The foundation of a building is that part of walls, piers and columns in direct contact with, and transmitting loads to, the ground. The building foundation is sometimes referred to as the artificial foundation, and the ground on which it bears as the natural foundation. Early buildings were founded on rock or firm ground; it was not until the beginning of the twentieth century that concrete was increasingly used as a foundation base for walls. With the introduction of local and then national building regulations, standard forms of concrete foundations have become accepted practice in the UK, along with more rigorous investigation of the nature and bearing capacity of soils and bedrock.

3.1 Functional requirements

The primary functional requirement of a foundation is strength and stability.

Strength and stability

The combined, dead, imposed and wind loads on a building must be transmitted to the ground safely, without causing deflection or deformation of the building or movement of the ground that would impair the stability of the building and/or neighbouring structures. Foundations should also be designed and constructed to resist any movements of the subsoil.

Foundations should be designed so that any settlement is both limited and uniform under the whole of the building. Some settlement of a building on a soil foundation is inevitable. As the building is erected the loads placed on the foundation increase and the soil is compressed. This settlement should be limited to avoid damage to service pipes and drains connected to the building. Bearing capacities for various rocks and soils are assumed and these capacities should not be exceeded in the design of the foundation to limit settlement.

3.2 Bedrock and soil types

Ground is the general term for the Earth's surface, which varies in composition within the two main groups: rocks and soils. Rocks include hard, strongly cemented deposits such as granite, and soils the loose un-cemented deposits such as clay. Rocks suffer negligible compression and soils measurable compression under the imposed load of a building. The size and depth of a foundation is

determined by the structure and size of the building it supports and also the nature and bearing capacity of the ground supporting it.

Rocks

Rocks may be divided into three broad groups as igneous, sedimentary and metamorphic.

Igneous rocks

Igneous rocks, such as granite, dolerite and basalt, are those formed by the fusion of minerals under great heat and pressure. Beds of strong igneous rock occur just below or at the surface of the ground in Scotland and Cornwall as Aberdeen and Cornish granite respectively. The nature and suitability of such rocks as a foundation may be distinguished by the need to use a pneumatic drill to break up the surface of sound, incompressible rock to form a roughly level bed for foundations. Because of the density and strength of these rocks it would be sufficient to raise walls directly off the rock surface. For convenience it is usual to cast a bed of concrete on the roughly levelled rock surface as a level surface on which to build. The concrete bed need be no wider than the wall thickness it supports.

Sedimentary rocks

Sedimentary rocks, such as limestone and sandstone, are those formed gradually over thousands of years by the settlement of particles of calcium carbonate or sand to the bottom of bodies of water where the successive layers of deposit have been compacted as beds of rock by the weight of water above. Because of the irregular and varied deposit of the sediment, these rocks were formed in layers or laminae. In dense rock beds the layers are strongly compacted and in others the layers are weakly compacted and may vary in the nature of the layers and so have poor compressive strength. Because of the layered nature of these rocks the material should be laid as a building stone with the layers at right angles to the loads.

Metamorphic rocks

Metamorphic rocks such as slates and schists are those changed from igneous, sedimentary rocks or from soils into metamorphic rocks by pressure or heat or both. These rocks vary from dense slates in which the layers of the material are barely visible to schists in which the layers of various minerals are clearly visible and may readily split into thin plates. Because of the mode of the formation of these rocks the layers or planes rarely lie horizontally in the ground and so generally provide an unsatisfactory or poor foundation.

Soil

Soil is the general term for the upper layer of the Earth's surface that consists of various combinations of particles of disintegrated rock, such as gravel, sand or clay, with some organic remains of decayed vegetation generally close to the surface.

Topsoil

The surface layer of most of the low-lying land in the UK that is most suited to building, consists of a mixture of loosely compacted particles of sand, clay and an accumulation of decaying vegetation. This layer of topsoil, which is about 100 to 300 mm deep, is sometimes referred to as vegetable topsoil. It is loosely compacted, supports growing plant life and is unsatisfactory as a foundation because of its poor bearing capacity. It should be stripped from the site and retained for landscaping around the site.

Subsoil

Subsoil is the general term for soil below the topsoil. It is unusual for a subsoil to consist of gravel, sand or clay by itself. The majority of subsoils are mixes of various soils. Gravel, sand and clay may be combined in a variety of proportions. To make a broad assumption of the behaviour of a particular soil under the load on foundations it is convenient to group soils such as gravel, sand and clay by reference to the size and nature of the particles. The three broad groups are coarse-grained non-cohesive, fine-grained cohesive and organic. The nature and behaviour under the load on foundations of the soils in each group are similar.

Coarse-grained non-cohesive soils

Soils that are composed mainly of, or combinations of, sand and gravel consist of largely siliceous, unaltered products of rock weathering. They have no plasticity and tend to lack cohesion, especially when dry. Under pressure of the loads on foundations the soils in this group compress and consolidate rapidly by some rearrangement of the coarse particles and the expulsion of water. A foundation on coarse-grained non-cohesive soils settles rapidly by consolidation of the soil as the building is erected, so that there is no further settlement once the building is completed.

   Gravel consists of particles of a natural coarse-grained deposit of rock fragments and finer sand. Many of the particles are larger than 2 mm. Sand is the natural sediment of granular, mainly siliceous, products of rock weathering. Particles are smaller than 2 mm, are visible to the naked eye and the smallest size is 0.06 mm. Sand is gritty, has no real plasticity and can easily be powdered by hand when dry. Dense, compact gravel and sand requires a pick to excavate for foundation trenches.

Fine-grained cohesive soils

Fine-grained cohesive soils, such as clays, are a natural deposit of the finest siliceous and aluminous products of rock weathering. Clay is smooth and greasy to the touch, shows high plasticity, dries slowly and shrinks appreciably on drying. Under the pressure of the load on foundations clay soils are very gradually compressed by the expulsion of water through the very many fine capillary paths, so that buildings settle gradually during building work and this settlement may continue for some years after the building is completed. The initial and subsequent small settlement by compression during and after building on clay subsoils will generally be uniform under most small buildings, thus no damage is caused to the structure and its connected services.

3.3 Ground movement

Approved Document A states that the building shall be constructed so that ground movement caused by swelling, shrinkage or freezing of the subsoil, or land-slip or subsidence, which can be reasonably foreseen, will not impair the stability of the building. The foundations of the building must be selected and designed so that they overcome the problems of ground movement.

Volume change

Firm, compact shrinkable clays suffer appreciable vertical and horizontal shrinkage on drying and expansion on wetting due to seasonal changes. Seasonal volume changes under grass extend to about 1 m below the surface in Great Britain and up to depths of 4 m or more below large trees. The extent of volume changes, particularly in firm clay soils, depends on seasonal variations and the proximity of trees and shrubs. The greater the seasonable variation, the greater the volume change. The more vigorous the growth of shrubs and trees in firm clay soils, the greater the depth below surface the volume change will occur. As a rough guide it is recommended that buildings on shallow foundations should not be closer to single trees than the height of the tree at maturity, and one-and-a-half times the height at maturity of groups of trees, to reduce the risk of damage to buildings by seasonal volume changes in clay subsoils.

When shrubs and trees are removed to clear a site for building on firm clay subsoils there will, for some years after the clearance, be ground recovery as the clay gradually recovers moisture previously taken by the shrubs and trees. The design and depth of foundations of buildings must allow for this gradual expansion to limit damage by differential settlement. Similarly, if vigorous shrub or tree growth is stopped by removal, or started by planting, near to a building on firm clay subsoil with foundations at a shallow depth, it is most likely that gradual expansion or contraction of the soil will cause damage to the building by differential movement. Significant seasonal volume change,
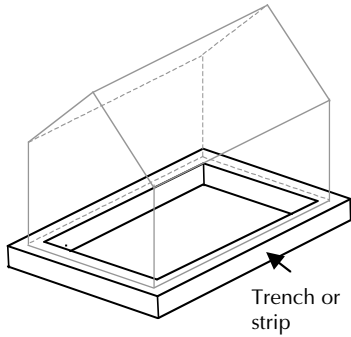
A Strip foundations

Used to transfer long continuous loads (such as walls). The width and depth of the foundation will depend on the nature of ground and building loads.
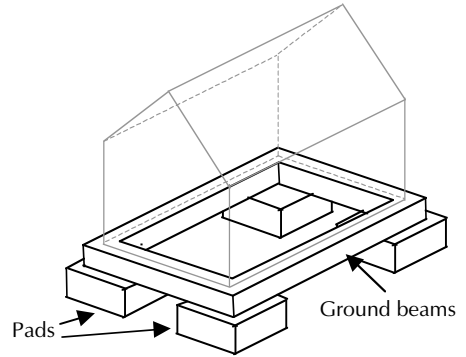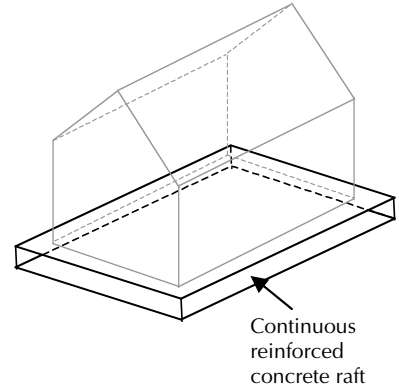
B Pad foundations

More commonly used under point loads such as columns, but can be used under ground beams to transfer continuous loads. The width and depth of each pad foundation will depend on the soil conditions and building loads.
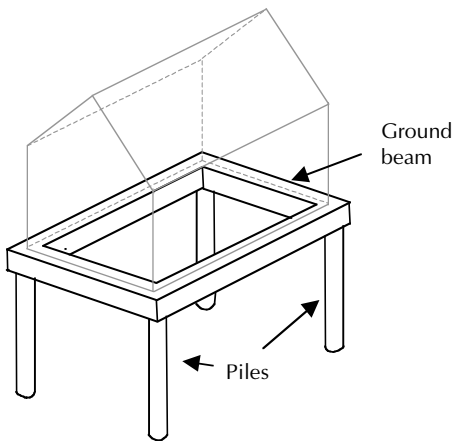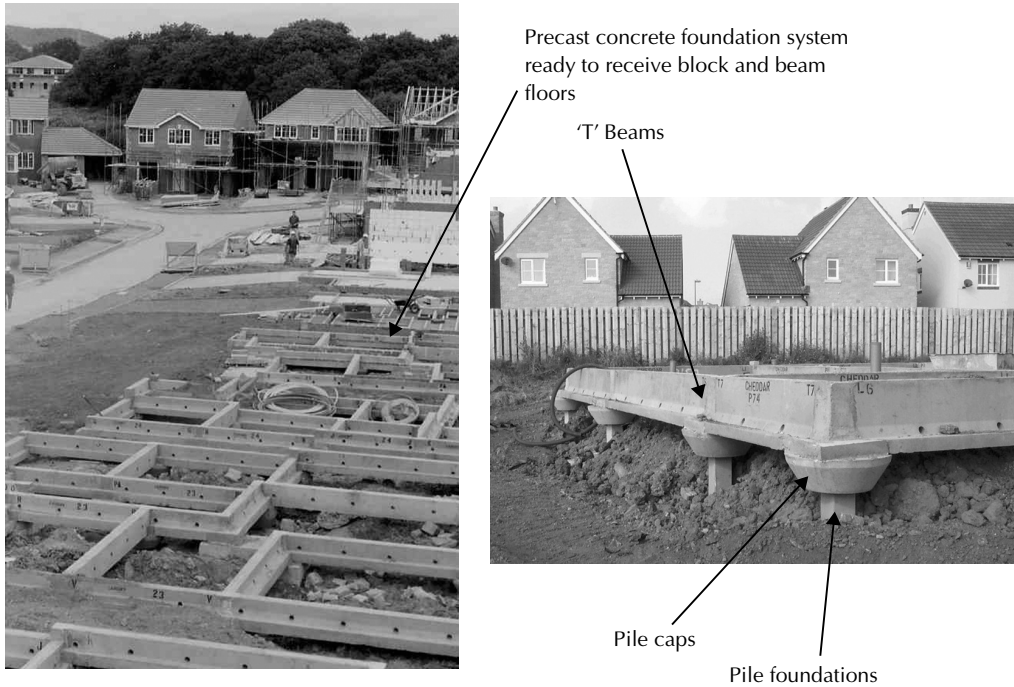
C Pile foundations

The pile foundation takes the load of the building through made-up ground or weak soil to load-bearing strata. Ground beams transfer the building loads to the piles.

D Raft foundations

Reinforced concrete raft foundations spread the load over the whole building area reducing the load per unit area. Raft foundations are used where building loads are high or ground conditions are poor.

Figure 3.1   Simple schematic of foundation types.

Precast concrete foundation system ready to receive block and beam floors

'T' Beams

Pile caps

Pile foundations

Photograph 3.1   Precast concrete foundations systems (www.roger-bullivant.co.uk).

due to deep-rooted vegetation, may be pronounced during periods of drought and heavy continuous rainfall.

The most economical and effective foundation for low rise buildings on shrinkable clays close to deep-rooted vegetation is a traditional system of short-bored piles and ground beams (Figure 3.1C) or the precast piles and beams such as those shown in Figure 3.2, Photograph 3.1. The piles should be taken down to a depth below which vegetation roots will not cause significant volume changes in the subsoil. Single deep-rooted vegetation such as shrubs and trees as close as their mature height to buildings, and groups of shrubs and trees one-and-a-half times their mature height to buildings, can affect foundations on shrinkable clay subsoils. When planting new trees and shrubs close to buildings proprietary root limiting products should be used (sometimes termed 'root protectors') to help prevent the spread of tree roots and hence provide some protection against damage to building foundations. Expert advice should be sought from a tree surgeon.

Frost heave

Where the water table is high, i.e. near to the surface, soils, such as silts, chalk, fine gritty sands and some lean clays may expand when frozen. This expansion is due to crystals of ice forming and expanding in the soil and so causing frost heave. In the UK, groundwater near the surface rarely freezes at depths of

more than 0.5 m, but in exposed positions on open ground during frost it may freeze up to a depth of 1 m. For unheated buildings and heated buildings with insulated ground floors, a foundation depth of 450 mm is generally sufficient against the possibility of damage by ground movement due to frost heave.

Made up ground

Areas of made up ground are often used for buildings as the demand for new buildings increases. Because of the varied nature of the materials tipped to fill and raise ground levels and the uncertainty of the bearing capacity of the fill, conventional foundations may be unsatisfactory and investigation is required to establish the most suitable foundation design. The bearing ground may be some distance below the surface level of the made up ground and to excavate for conventional strip foundations would be grossly uneconomic. A solution is the use of piers (piles) on isolated pad foundations supporting reinforced concrete ground beams on which walls are raised, as illustrated in Figure 3.1C.

Unstable ground

There are extensive areas of ground where mining and excavations for coal, chalk, sand and gravel may have made the ground unstable. Where such works have previously existed the ground and building foundations may well be subject to periodic, unpredictable subsidence. Specialist advice should always be sought to establish the extent of previous workings and the most appropriate method of designing foundations for such situations.

   Where it is known that ground may be unstable and there is no ready means of predicting the possibility of mass movement of the subsoil and it is expedient to build, a solution is to use some form of reinforced concrete raft under the whole of the buildings, as illustrated in Figure 3.1D. The concrete raft, which is cast on or just below the surface, is designed to spread the load of the building over the whole of the underside of the raft so that, in a sense, the raft floats on the surface. Alternatively, if there is good loadbearing strata, but they are some metres below the surface, pile foundations can be used.

Precast pile and beam foundation systems

Planning requirements that restrict the removal of trees and encourage building on brownfield sites have resulted in increased use of pile foundations for domestic developments. Precast concrete foundations are often used to overcome difficult ground conditions, problems caused by vegetation or where the speed of construction is important. 'Fast track' pile foundations systems have been developed that are suitable for both timber-framed and traditional masonry construction (Figure 3.2). The general trend towards mechanised installation of foundation systems helps to remove the risks associated with working in deep excavations, workers coming into contact with wet concrete and manual handling of heavy materials.
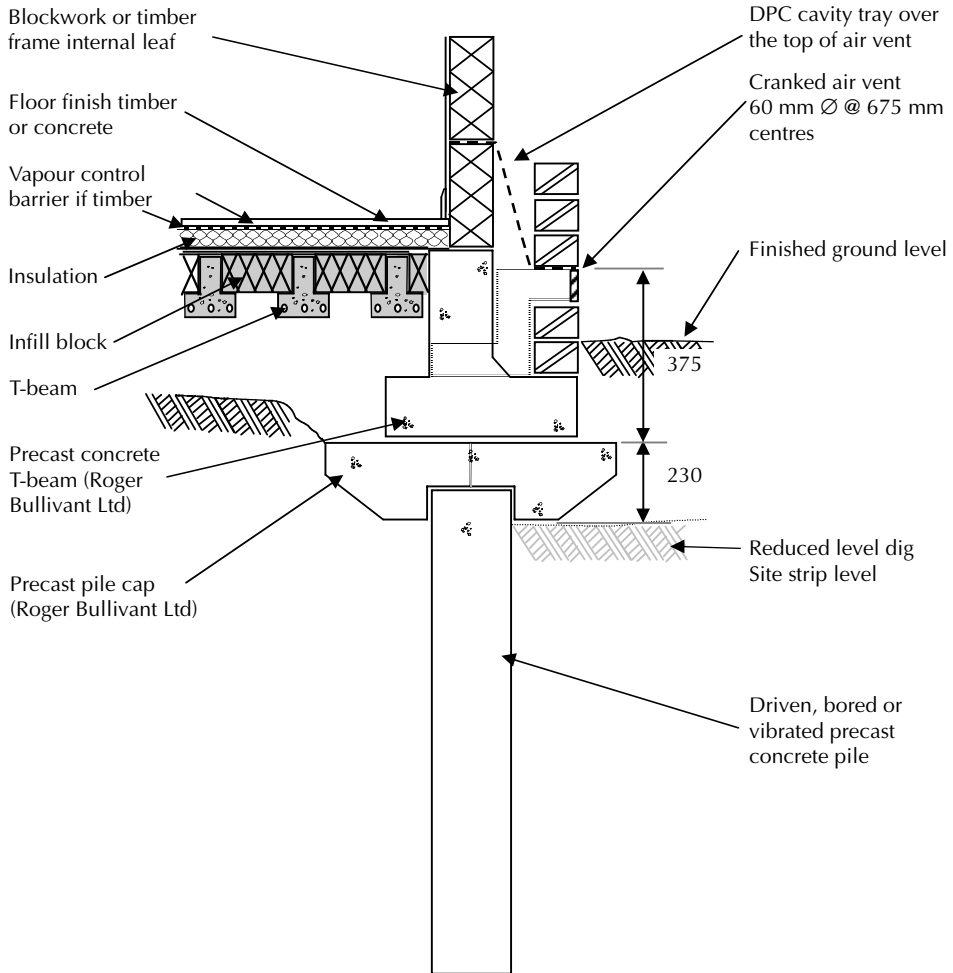
Figure 3.2   Precast concrete foundation system (adapted from www.roger-bullivant.co.uk)

Precast piles can be installed by a top driven hydraulic hammer. Once the correct resistance is achieved, the piles can be cropped to the correct level so that the pile caps and T beams can be quickly installed. Other types of pile may be used, according to ground conditions. These could be: driven steel, continuous flight auger (CFA) or a unique displacement auger pile (CHD).

3.4 Foundation construction

The move to closely regulated systems has resulted in the use of foundations that are less prone to problems than some earlier methods of construction.

One negative effect of this standardised approach is that some foundations may be over-designed for the loads they carry, either to avoid any possibility of foundation failure or simply through the application of inappropriate foundations for a particular building type. For example, it is not uncommon for timber-framed buildings to be built off foundations designed for heavier loadbearing masonry construction, essentially a lack of thought resulting in wasted materials and unnecessary expense.

There are a number of familiar approaches to foundation construction, from strip foundations, piles and rafts as described below (Figure 3.3), all of which are constructed of concrete.
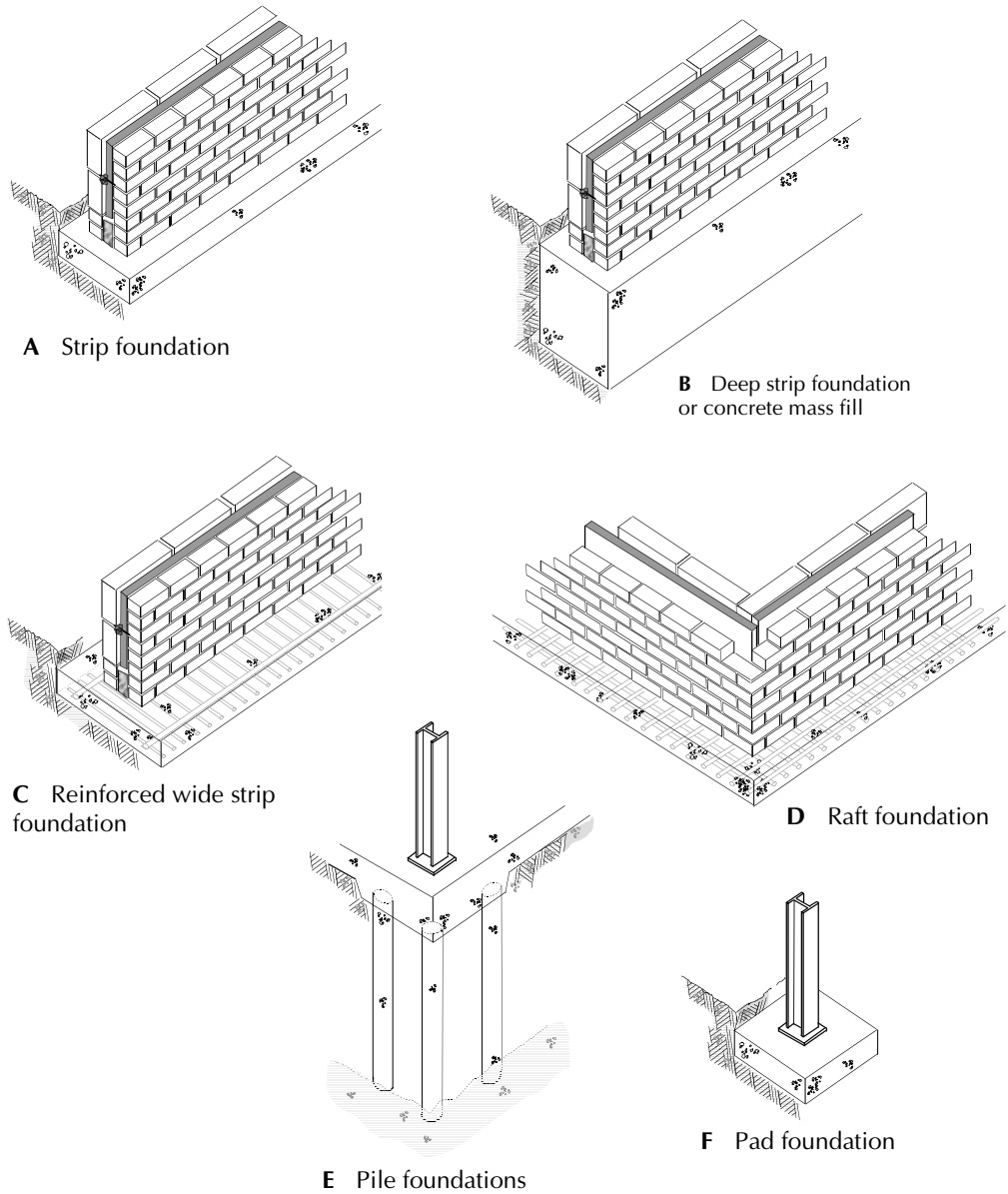
Concrete

Concrete is the name given to a mixture of particles of sand and gravel, the aggregate, bound together with cement, the matrix. Fine aggregate is natural sand, which has been washed and sieved to remove particles larger than 5 mm, and coarse aggregate is gravel that has been crushed, washed and sieved so that the particles vary from 5 mm up to 50 mm in size. The fine and coarse aggregate are delivered separately. By combining them in the correct proportions, a concrete with very few voids or spaces in it can be made that produces a strong concrete.

The cement most used is ordinary Portland cement. It is manufactured by heating a mixture of finely powdered clay and limestone with water to a temperature of about 1200°C, at which the lime and clay fuse to form a clinker. This clinker is ground with the addition of a little gypsum to a fine powder of cement. Cement powder reacts with water and its composition gradually changes; the particles of cement bind together and adhere strongly to materials with which they are mixed. Cement hardens gradually after it is mixed with water. Some thirty minutes to an hour after mixing with water the cement is no longer plastic and it is said that the initial set has occurred. About 10 hours after mixing with water, the cement has solidified and it increasingly hardens to a dense solid mass after 7 days.

Water–cement ratio

The materials used for making concrete are mixed with water for two reasons: first to cause the reaction between cement and water, which results in the cement acting as a binding agent and, secondly, to make the material sufficiently plastic to be easily placed in position. The ratio of water to cement used in concrete affects its ultimate strength. If too little water is used the concrete is so stiff that it cannot be compacted and if too much water is used the concrete does not develop full strength. Very little water is required to ensure that a full chemical reaction takes place within the concrete mix. Any excess water will not be used and will leave very small voids within the concrete when the unused water eventually evaporates away. The water added must be sufficient to

A Strip foundation

B Deep strip foundation
or concrete mass fill

C Reinforced wide strip
foundation

D Raft foundation

E Pile foundations

F Pad foundation

Figure 3.3   Foundation types.

allow the chemical reaction to take place and enable the concrete to be worked
(poured or vibrated) into place. The amount of water required to make concrete
sufficiently plastic (workable) depends on the position in which the concrete
is to be placed. Plasticisers are added to the concrete mixture and enable the
concrete to be more workable and fluid without increasing the quantities of

water used. Using plasticisers keeps the strength of the concrete high without increasing the quantity of cement.

Concrete mixes

The materials used in reinforced concrete are commonly weighed and mixed in large concrete mixers. It is not economical for builders to employ expensive concrete mixing machinery for small buildings and the concrete for foundations, floors and lintels is usually delivered to site ready mixed, except for small batches that are mixed by hand or in a portable mixer.

British Standard 5328: specifying concrete, including ready-mixed concrete, gives a range of mixes. One range of concrete mixes in the Standard, ordinary prescribed mixes, is suited to general building work such as foundations and floors. These prescribed mixes should be used in place of the traditional nominal volume mixes such as 1:3:6 cement, fine and coarse aggregate by volume, which have been used in the past. The prescribed mixes, specified by dry weight of aggregate, used with 100 kg of cement, provide a more accurate method of measuring the proportion of cement to aggregate and, as they are measured against the dry weight of aggregate, allow for close control of the water content and therefore the strength of the concrete.

Prescribed mixes are designated by the letters and numbers C7.5P, C10P, C15P, C20P, C25P and C30P; the letter C stands for 'compressive', the letter P for 'prescribed' and the number indicates the 28-day characteristic cube crushing strength in newtons per square millimetre (N/mm^2) that the concrete is expected to attain. The prescribed mix specifies the proportions of the mix to give an indication of the strength of the concrete sufficient for most building purposes, other than designed reinforced concrete work.

Table 3.1 equates the old nominal volumetric mixes of cement and aggregate with the prescribed mixes and indicates the uses for these mixes.

Ready-mixed concrete

Ready-mixed concrete plants are common and are able to supply to all but the most isolated building sites. These plants prepare carefully controlled concrete mixes, which are delivered to site by lorries on which the concrete is churned to

Table 3.1   Concrete mixes

Nominal volume mix	BS 5328 Standard mixes	Uses
1:8 all-in 1:3:6	ST1	Foundations
1:3:6 1:2:4	ST2 ST3	Site concrete
1:1$\frac{1}{2}$:3	ST4	Site concrete reinforced

delay setting. The standard lorries, which hold the concrete mixers, deliver up to 6 m^3 loads; however, some plants do have 8 m^3 lorries, and smaller lorries of 4 m^3 and less for occasional small loads.

To order ready-mixed concrete it is necessary to specify only the prescribed mix, for example C10P, the cement, type and size of aggregate and workability. The workability required will depend on the situation where the concrete is to be used. Very stiff mixes (low workability) are used to bed kerb stones, concrete flags, road gullies and slabs. If highly workable and fluid mixes were used in these situations the precast concrete units would simply sink through the concrete. However, when a stiff mix is used, the precast or stone units can be easily bedded at the correct level. If concrete needs to be poured into deep formwork, which has considerable reinforcement, the concrete needs to be sufficiently fluid to pass through the gaps in the reinforcement to the bottom of the formwork.

Soluble sulphates

There are water soluble sulphates in some soils, such as plastic clay, which react with ordinary cement and in time will weaken concrete. Sulphate-resistant cements are more resistant to the destructive action of sulphates. Sulphate-resisting Portland cement has a reduced content of aluminates that combine with soluble sulphates in some soils and is used for concrete in contact with those soils.

Strip foundations

Strip foundations consist of a continuous strip, usually of steel reinforced concrete, formed centrally under loadbearing walls. This continuous strip serves as a level base on which the wall is built and is of such a width as is necessary to spread the load on the foundations to an area of subsoil capable of supporting the load without undue compaction. The bearing capacity of the soil should be greater than the loads imposed by the buildings foundation.
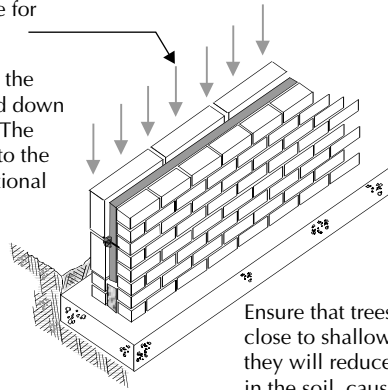
Figure 3.4 illustrates a strip foundation. The continuous strip of concrete is spread in the trenches excavated down to an undisturbed level of compact soil. The strip of concrete may well need to be no wider than the thickness of the wall. In practice the concrete strip will generally be wider than the thickness of the wall for the convenience of covering the whole width of the trench and to provide a wide enough level base for bricklaying below ground. A continuous strip foundation of concrete is the most economic form of foundation for small buildings on compact soils. (See Photograph 3.2.)

The width of a concrete strip foundation depends on the bearing capacity of the subsoil and the load on the foundations: the greater the bearing capacity of the subsoil, the less the width of the foundation and vice versa. Table 3.2 (from Approved Document A) sets out the recommended minimum width of concrete strip foundations related to six specified categories of subsoil and calculated total loads on foundations.

Strip foundations are suitable for continuous loads.

For cavity wall construction, the building loads are transferred down the inner skin of the cavity. The cavity ties tie the inner wall to the external skin providing additional stability.

Strip foundations, at a shallow depth, are suitable for good load-bearing strata, where the moisture content of the soil is stable.

Ensure that trees are not planted close to shallow foundations as they will reduce moisture content in the soil, causing clays to contract and the foundation to settle as the soil shrinks.

Figure 3.4   Strip foundation.

The dimensions given in Table 3.2 are indicative of what might be acceptable in the conditions specified rather than absolutes to be accepted regardless of the conditions prevailing on individual sites. Figure 3.5A and B illustrate the important dimensions.

The strip foundation for a cavity external wall and a solid internal, load bearing wall illustrated in Figure 3.6 would be similar to the width recommended in the Approved Documents for a firm clay subsoil when the load on the foundations is no more than 50 kN/linear metre. In practice the linear load on the foundation of a house would be appreciably less than 50 kN/linear metre and the foundation may well be made wider than the minimum requirement for the convenience of filling a wider trench with concrete, due to the width of the excavator's bucket, or for the convenience of laying brick below ground, allowing adequate working space.

If the thickness of a concrete strip foundation (without steel reinforcement) were appreciably less than its projection each side of a wall, the concrete might fail through the weight of the wall causing a 45° shear crack as illustrated in Figure 3.7. If this occurred the bearing surface of the foundation on the ground would be reduced to less than that necessary for stability. Concrete has few tensile properties and is only good in compression. In Figure 3.7 where the load is place directly on top of the concrete foundation and compressed between the ground, the foundation remains stable. However, the concrete outside the 45° angle (where compressive forces are distributed) experiences some tension as the reaction of the ground attempts to lever the foundation upwards, thus the foundation would fail.

Stepping strip foundations

Where strip foundations are used on sloping sites it may be necessary to step the foundation (Figure 3.8). In order to step the foundation, the full thickness

The trenches for the foundations are excavated.

A continuous membrane is then laid over the whole area of the building. Traditionally the membrane would be used to prevent the penetration of damp into the building, nowadays such barriers are often used to prevent gases as well as moisture entering into the dwelling. The membrane or damp proof membrane (DPM) acts as a barrier separating the building from the ground.

The reinforcement for the trench foundation (ground beam) is then positioned in line and at the correct level. The main trenches and beams will be positioned under loadbearing walls.

Spacers are used to hold the reinforcement off the ground. This allows concrete to go underneath the reinforcement ensuring adequate cover all around the reinforcement.

Ensuring the steel reinforcement is correctly positioned within the concrete will mean that they can bond together. The matrix formed between the reinforcement and concrete allows the foundation to deal with both the compressive and tensile forces. If the steel did not bond with the concrete the forces would not be able to transfer from one material to the other and the foundation would fail.

The trench foundations are poured up to the underside of the floor slab. The internal blockwork wall can then be built up to floor level; this will act as edge support when the concrete floor is poured.

Part of the ground beam reinforcement remains uncovered during this stage. This will eventually be cast into the floor forming a complete reinforced concrete ground beam.

Light steel mesh reinforcement will be placed over the whole of the floor slab. This will prevent the concrete slab cracking if the ground between the ground beams settles.

Finally, the floor slab is cast and levelled off and the external cavity wall is built up to DPC (damp proof course) level.

Photograph 3.2   Trenches and ground beams. Source: www.leedsmet.ac.uk/teaching/vsite

Table 3.2 Minimum width of strip foundations

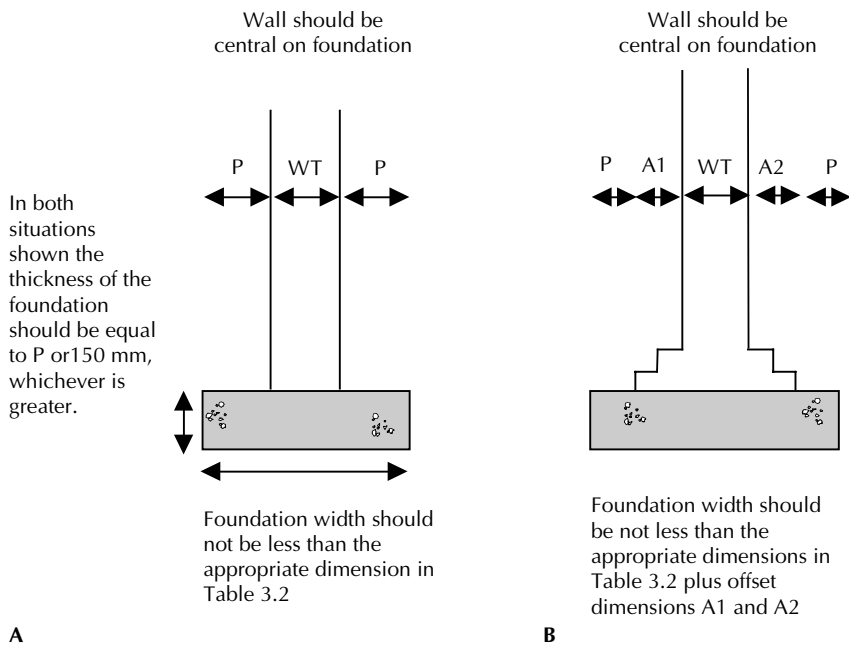| Types of subsoil	Condition of subsoil	Field test applicable	Total load of load-bearing walling – not more than (kN/linear metre)					
			Minimum width of strip foundation (mm)					
			20	30	40	50	60	70
Rock	Not inferior to sandstone, limestone or firm chalk	Requires at least a mechanically operated pick for excavation	Equal to the width of the wall					
Gravel Sand	Compact Compact	Requires pick for excavation. Wooden peg 50 mm square cross-section hard to drive in beyond 150 mm	250	300	400	500	600	650
Clay Sandy clay	Stiff Stiff	Cannot be moulded with the fingers and requires pick for removal	250	300	400	500	600	650
Clay Sandy clay	Firm Firm	Can be moulded by substantial pressure with fingers, can be excavated with a spade	300	350	450	600	750	850
Sand Silty sand Clayey sand	Loose Loose Loose	Can be excavated with a spade. Wooden peg 50 mm × 50 mm cross-section easily driven	400	600	When the loads exceed 30 kN/linear metre in such weak soil conditions, the widths of strip foundations are not specified in the Building Regulations. Alternative types of foundation would be more suitable.			
Silt Clay Sandy clay Silty clay	Soft Soft Soft Soft	Fairly easy to mould with fingers. Easy to excavate	450	650				
Silt Clay Sandy clay Silty clay	Very soft Very soft Very soft Very soft	Extrudes between fingers when squeezed	600	850				

Source: Approved Document A, 2000

Wall should be
central on foundation

Wall should be
central on foundation

In both
situations
shown the
thickness of the
foundation
should be equal
to P or 150 mm,
whichever is
greater.

P   WT   P

P   A1   WT   A2   P

Foundation width should
not be less than the
appropriate dimension in
Table 3.2

Foundation width should
be not less than the
appropriate dimensions in
Table 3.2 plus offset
dimensions A1 and A2

A   **B**

Figure 3.5   A & B Foundation dimensions (adapted from Approved Document A).

cavity wall

internal load
bearing wall

450 mm min

450 mm min

min 150 mm
thick strip
concrete
foundation
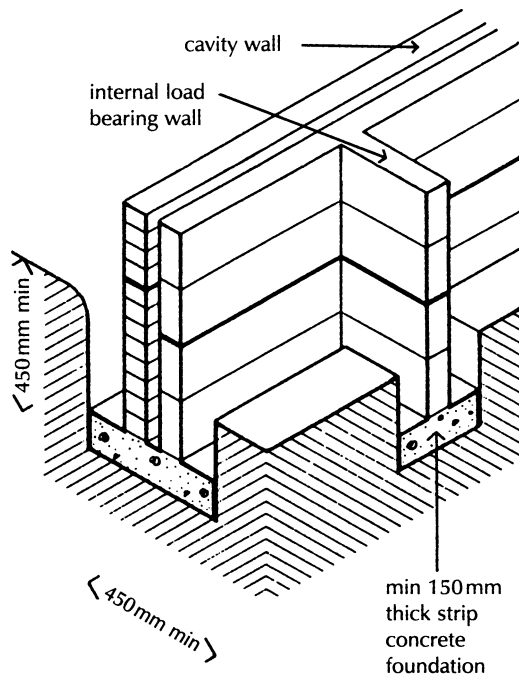
Figure 3.6   Strip foundation.

Strip foundation

If P is greater than T, then the foundation may shear at 45° reducing the width of the foundation and bearing area.

The foundation fails where tension is exerted on the concrete.

P

T

Shear failure angle 45°.

Following the shear failure, the load is concentrated on a smaller area, the ground may consolidate under the increased load.
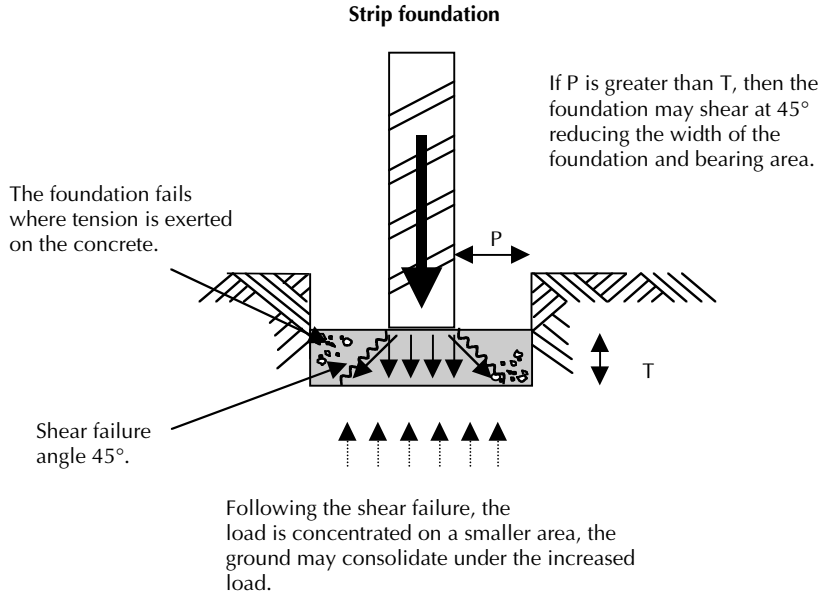
Figure 3.7   Shear failure in a strip foundation.

of the upper foundation should overlap twice the height of the step (thickness of upper foundation), or 300 mm, whichever is greater.

When stepping foundations consideration should also be given to the brickwork and blockwork that will be built on top of the foundation. The brickwork and blockwork should tie in at the step to avoid the need for cutting bricks and blocks and also to avoid the possibility of reducing the stability of the wall, as illustrated in Figure 3.9.

Minimum overlap L = twice height of step or 300 mm whichever is greater

L

S

T

The step (S) should not be greater than the foundation depth (T).
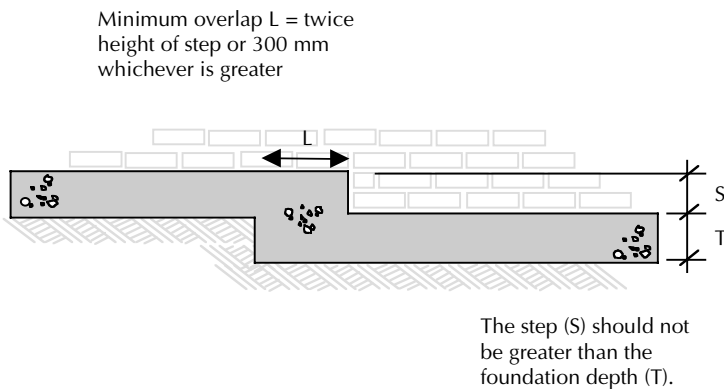
Figure 3.8   Stepped strip foundations.

Modular heights
Brick 65 + 10 mm
Blocks 215 + 10 mm
Blocks laid flat 100 + 10 mm
Blocks laid flat 150 + 10 mm

Walling selected so that the courses tie in with the step

Different heights can be achieved by selecting a combination of bricks and blocks, e.g. to accommodate a step of 300 mm a course of bricks and a course of blocks can be used.
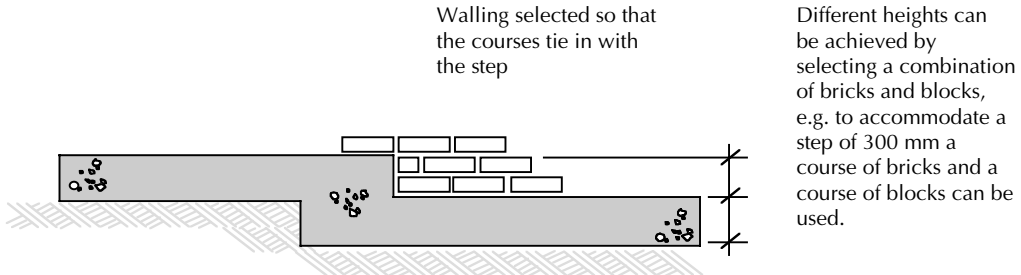
Figure 3.9 Brick coursing to stepped foundations.

Wide strip foundation

Distributing the load over a larger area reduces the load per unit area on the ground. Strip foundations on subsoils with poor bearing capacity, such as soft sandy clays, may need to be considerably wider than traditional (narrow) strip foundations. However, to keep increasing the width and depth of the concrete ensuring that the foundation does not shear makes the process uneconomical. The alternative is to form a strip of steel-reinforced concrete, illustrated in Figures 3.10 and 3.11.

Solid external wall

reinforcement

wide strip reinforced concrete foundation
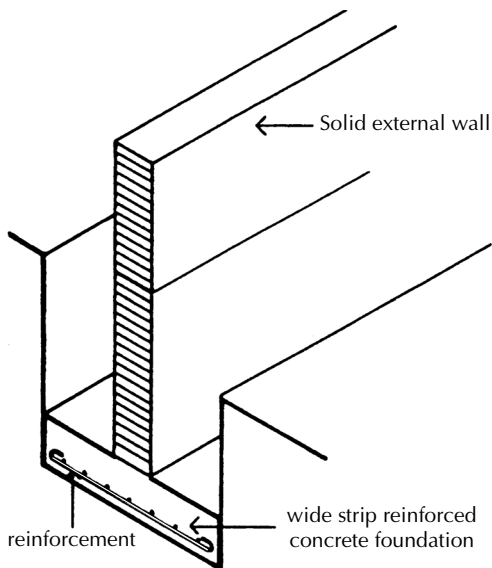
Figure 3.10 Wide strip foundation.

The tensile reinforcement allows the width of the foundation to be increased and the loads to be distributed over a greater area

Steel reinforcement is placed in the bottom of the foundation where tensile forces are experienced.
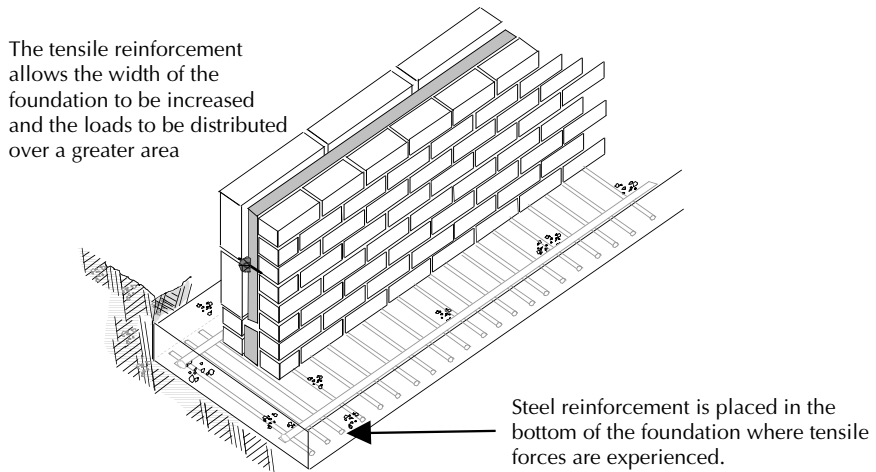
Figure 3.11 Steel reinforced wide strip foundation.

Concrete is strong in compression, but is weak in tension. The effect of the downward pressure of the wall on the middle of the foundation and the opposing force of the ground spread across the base of the foundation attempts to bend the foundation upwards; this places the top of the foundation in compression and the base of the foundation in tension.

These opposing pressures will tend to cause the shear cracking illustrated in Figure 3.12. To add tensile properties to the foundation steel, reinforcing bars are cast in the lower edge where tension will occur. There has to be a

Load

The load of the building is transferred though the wall to the foundation.

As the load is distributed through the foundation, the ground resists the force.

The result of the central load from the wall and the evenly distributed reaction from the ground attempts to bend the foundation.

The top of the foundation is placed under compression.

The bottom of the foundation experiences tensile forces.

Ground resists load

Figure 3.12 Distribution of forces in strip foundations.

Load

Main reinforcement placed at the base of the foundation where tensile forces are experienced.

Reinforcement resists bending stretching force in the base of the foundation.
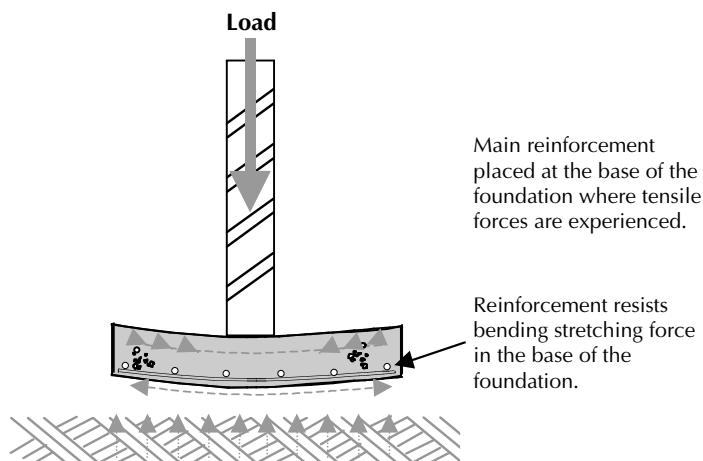
Figure 3.13   Accommodating tensile forces within strip foundations.

sufficient cover of concrete below the steel reinforcing rods to ensure a good bond between the concrete and steel and to protect the steel from corrosion. The steel and concrete make up a composite material that can resist both tensile and compressive forces. It is essential that the steel is placed where the tensile forces occur, see Figure 3.13.

Narrow strip (trench fill or deep strip) foundation

Stiff clay subsoils have good bearing strength and are subject to seasonal volume change. Because of seasonal changes and the withdrawal of moisture by deep rooted vegetation (such as shrubs and trees) it is practice to adopt a foundation depth of at least 0.9 m to provide a stable foundation. Although the base of a deep strip foundation will go to a depth where the clay soil is unaffected by seasonal changes in moisture content, the soil at the external face of the foundation will still expand and contract as it becomes saturated and dries out. To prevent lateral pressure being applied to the side of the foundation, a 50 mm thick compressible sheet material may be used (Figure 3.14).

Because of the good bearing capacity of the clay, the foundation may need to be little wider than the thickness of the wall to be supported. Trenches are usually formed by using mechanical excavators, thus the width of the trench is determined by the width of the excavator bucket available, which should not be less than the minimum required width of foundation. The trench is filled with concrete as soon as possible so that the sides of the trench do not fall in and the exposed clay bed does not dry out and shrink (as illustrated in Figure 3.15A). Where the trench is particularly wide and it is uneconomical to fill the whole trench with concrete it is common practice to use trench blocks. The trench blocks are laid flat and are often the full width of the walling above them (as illustrated in Figure 3.15B).

Strip foundation suitable for continuous loads carried through walls.

If expansion of clay is expected, compressible sheeting is used to stop clay soils exerting lateral pressure on the deep foundation.

Weak upper layer of subsoil or clay soils susceptible to expansion and contraction due to changes in moisture content.

Stable load bearing strata

Foundation depth increased taking the base of the foundation to a stronger load bearing strata or to a depth where the moisture content of the ground is unaffected by seasonal variation.

Figure 3.14   Deep strip or mass fill strip foundation.

Built up with concrete

Built up with trench blocks

Area above main foundation filled with concrete

Area above main foundation filled with trench blocks

A

B
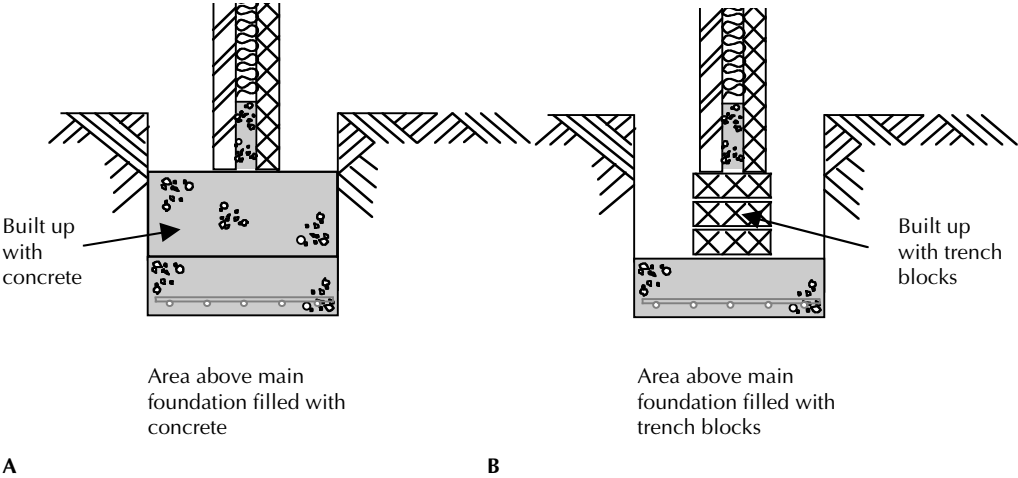
Figure 3.15   A & B Use of trench fill and trench blocks in strip foundations.

Short bored pile foundations

Where the subsoil is of firm, shrinkable clay, which is subject to volume change due to deep rooted vegetation for some depth below the surface and where the subsoil is of soft, or uncertain bearing capacity for a few metres below the surface, it may be economic and satisfactory to use a system of short bored piles as a foundation (Figure 3.16). Piles are concrete columns, which are either precast and driven (hammered) into the ground or cast in holes that are augured (drilled) into the ground down to a level of a firm, stable stratum of subsoil (Figure 3.17).

The piles that are excavated to a depth of 4 m below the surface are termed short bore, which refers to the comparatively short length of the piles as compared to the much longer piles used for larger buildings. Short bored piles are generally from 2 to 4 m long and from 250 to 350 mm diameter.

Holes are augered into the ground by machine. An auger is a form of drill comprising a rotating shaft with cutting blades that screw into the ground. The soil is either withdrawn and lifted to the surface as the shaft rotates or, with small augers, once the auger has cut into the ground it is withdrawn and the soil removed from the blades. The advantage of this system of augered holes is that samples of the subsoil are withdrawn, from which the nature and bearing capacity of the subsoil may be assessed. The piles may be formed of concrete or, more usually, a light steel cage of reinforcement is lowered into the hole and concrete poured or pumped into the hole and compacted
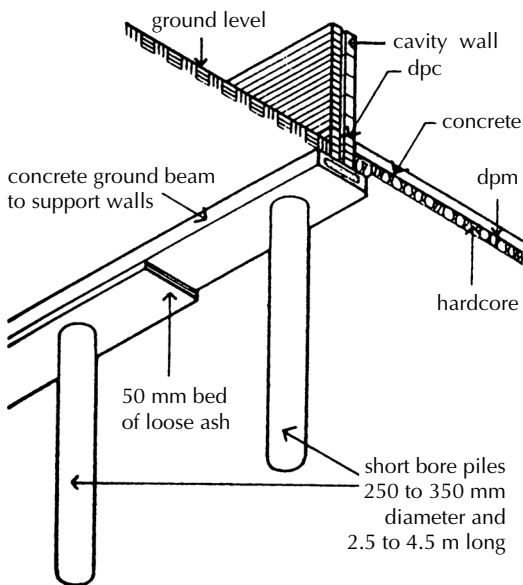
Figure 3.16   Short bored pile foundation (worm's eye view).

Point loads of columns transferred to pile cap then to pile foundations.

Any continuous loads applied through walls are transferred along reinforced concrete beams to the pile cap.

Pile cap

Cluster of piles

Pile foundations are used to transfer the load of the building to a more stable load-bearing stratum.

Short piles, often termed short bored piles, may be used to take the loads to soils that are unaffected by seasonal changes in moisture content.

Stable load-bearing stratum

Figure 3.17   Pile foundations.

to form a pile foundation. The piles are cast underneath the corners and intersection of loadbearing walls and at regular intervals between to reduce the span and depth of the reinforced ground beam, which transfers the wall and building loads to the foundation. A reinforced concrete ground beam is then cast over the piles as illustrated in Figure 3.18. The spacing of the piles depends on the loads to be supported and on economic sections of ground beam, see Figure 3.18.

Pad foundations

Pad foundations can be used to carry point loads or can be designed so that the loads of the walls and the buildings are transferred through ground beams that rest on pad foundations. The pad foundations transfer the loads to a lower

Imposed loads transferred through internal skin of cavity wall and internal walls.

Pile caps transfer loads from building and beams.

Reinforced short bore piles 250 to 350 mm diameter and 2.5 to 4.5 m deep, depending on the depth that good load bearing strata occur.

Weak strata

Load-bearing strata
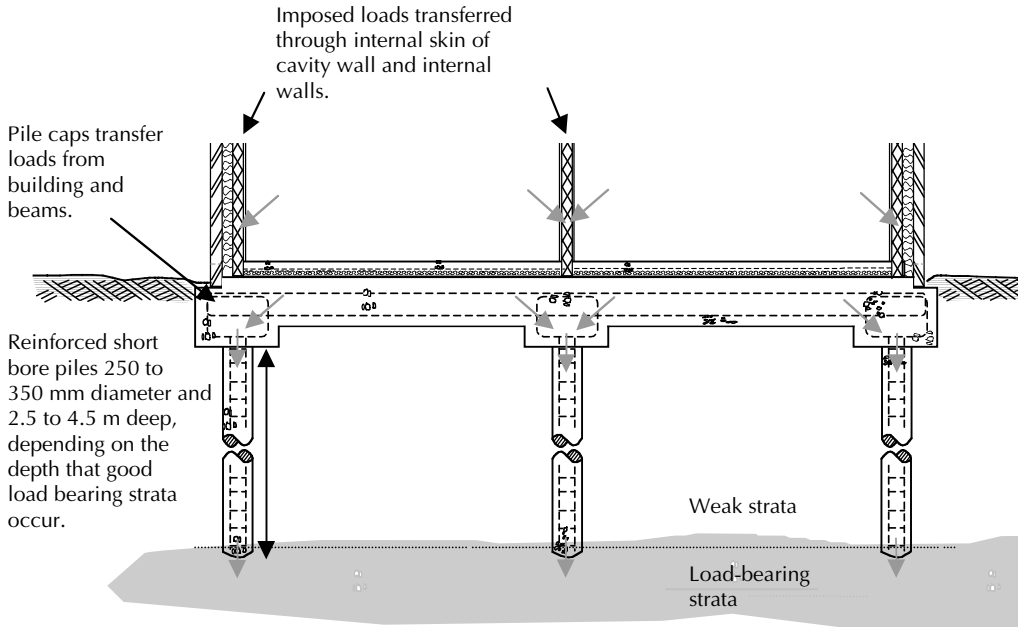
Figure 3.18   Section illustrating pile foundations.

level where soil of sufficient loadbearing strata exists (Figure 3.19). The width of a pad foundation can be increased to distribute the loads over a greater area, thus reducing the pressure on the ground. Photograph 3.3 shows the excavation sequence of pad foundations and ground beams.

On made up ground and ground with poor bearing capacity where a firm, natural bed of strata, for example, gravel or sand is some few metres below the surface, it may be economic to excavate for isolated piers of brick or concrete to support the load of buildings. The piers will be built at the angles, intersection of walls and under the more heavily loaded wall such as that between windows up the height of the building.

Pits are excavated down to the necessary level, the sides of the excavation temporarily supported and isolated pads of concrete are cast in the bottom of the pits. Brick piers or reinforced concrete piers are built or cast on the pad foundations up to the underside of the reinforced concrete beams that support walls as illustrated in Figure 3.20. The ground beams or foundation beams may be just below or at ground level, the walls being raised off the beams.

The advantage of this system of foundation is that pockets of tipped stone or brick and concrete rubble that would obstruct bored piling may be removed as the pits are excavated and that the nature of the subsoil may be examined

Point loads from
columns transferred to
pad foundation

Any continuous loads
applied through walls are
transferred along reinforced
concrete beams to the pad
foundation.

Ground beam

Pad foundation

Stable load-bearing stratum
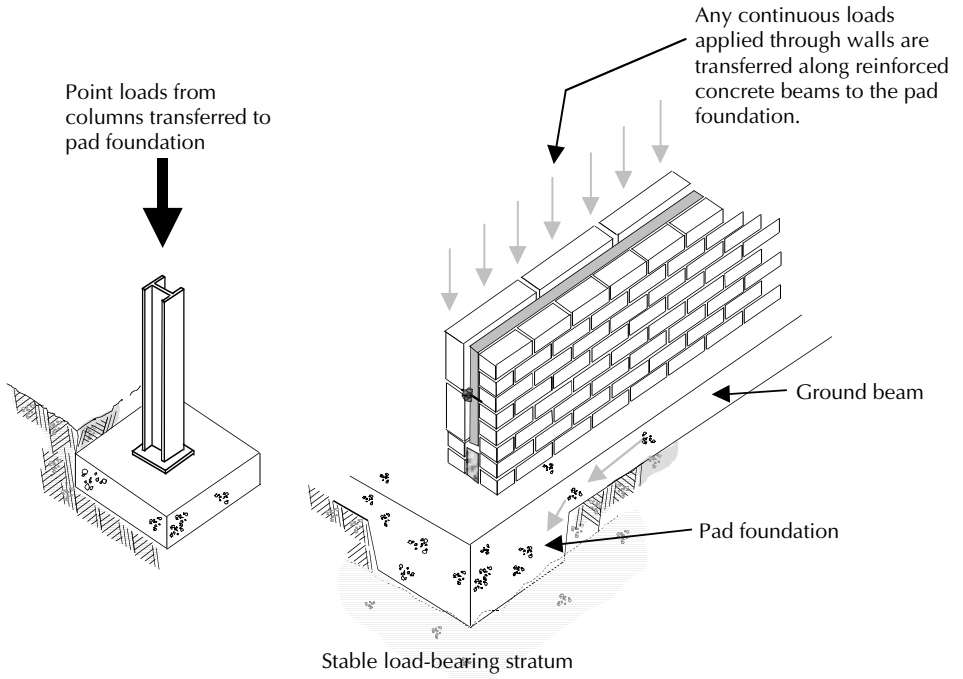
Figure 3.19   Pad foundations.

walls raised
off concrete
ground beam

external wall

concrete
on hardcore

piers support
reinforced concrete
ground beams
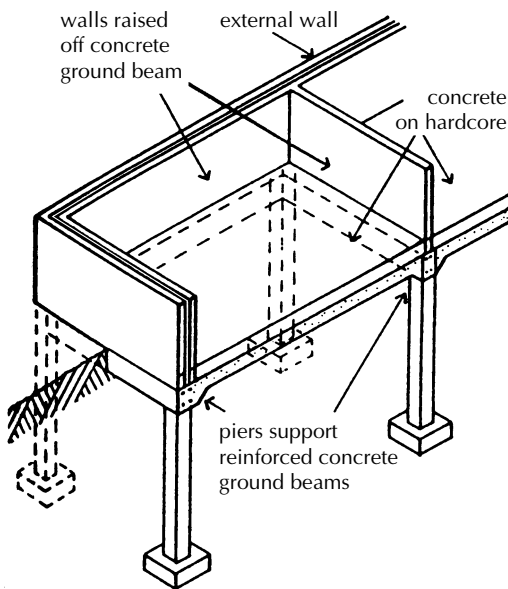
Figure 3.20   Pad foundations.

A   The foundation is marked out and excavated to the correct level. The machine operator attempts to keep the sides of the excavation as true and square as possible.

B   This pad foundation has been excavated down to good loadbearing strata. The bottom of the foundation is clean and ready for inspection by the building control officer.
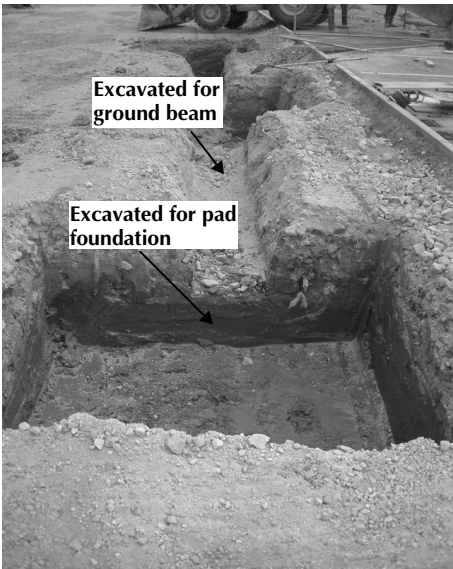
C   Once one pad foundation is complete, the ground beam, which spans between the pad foundations, is excavated, then the next pad foundation is dug out.
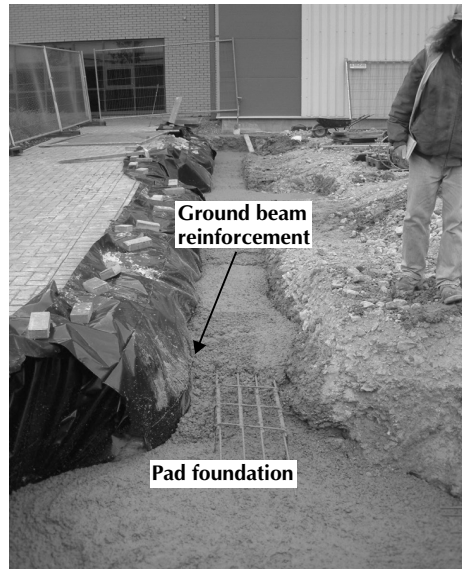
D   The reinforcement is placed in the ground beam foundation, positioned correctly and then the concrete is poured to the correct level. The concrete should be vibrated to remove air bubbles.

Photograph 3.3   Excavation and casting of pad foundation and ground beam.

Once the foundations have set the building can be constructed on top of them.

The columns are a point load and are positioned and bolted to the pad foundation.

The walls, which span between the columns, rest on the ground beam. The loads from the walls are transferred via the ground beam to the pad foundation.

Column

Pad foundation

Wall carried by ground beam

DPC
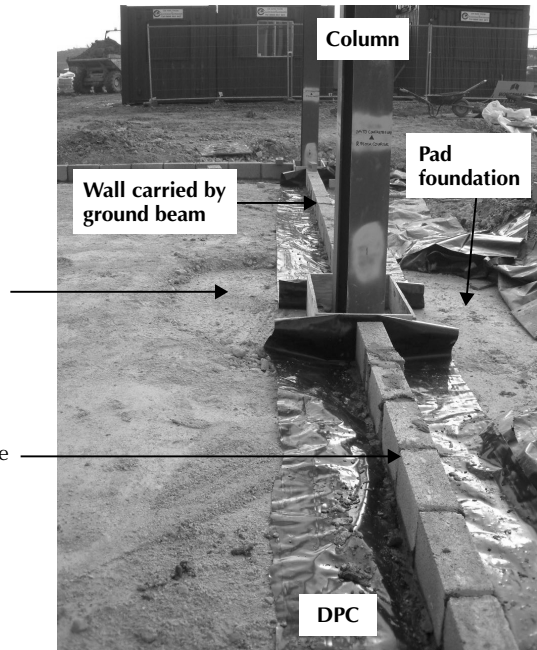
E   The loads from the columns (point loads) and walls (distributed loads) are transferred to the foundations

Photograph 3.3   (*continued*).

as the pits are dug to select a level of sound subsoil. This advantage may well be justification for this labour intensive and costly form of construction.

Raft foundations

A raft foundation consists of a raft of reinforced concrete under the whole of a building. Raft foundations may be used for buildings on compressible ground such as very soft clay, alluvial deposits and compressible fill material where strip, pad or pile foundations would not provide a stable foundation without excessive excavation. The reinforced concrete raft is designed to transmit the load of the building and distribute the load over the whole area under the raft, reducing the load per unit area placed on the ground (Figure 3.21). Distributing the loads in this way causes little, if any, appreciable settlement. The two types of raft foundation commonly used are the flat raft and the wide toe raft.

The flat slab raft is of uniform thickness under the whole of the building and reinforced to spread the loads from the walls uniformly over the under surface to the ground. This type of raft may be used under small buildings such as bungalows and two storey houses where the comparatively small loads on foundations can be spread safely and economically under the rafts. The

The load is distributed over the whole area of the building

Steel reinforcement runs in both
directions under the whole floor
area of the building
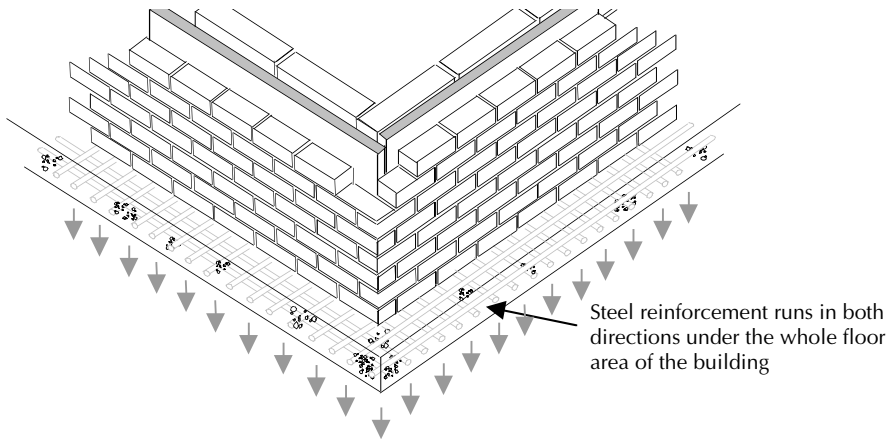
Figure 3.21   Raft foundation.

concrete raft is reinforced top and bottom against both upward and downward
bending. The construction sequence is as follows.

(1) Vegetable topsoil is removed.
(2) A blinding layer of concrete 50 mm thick is spread and levelled to provide
     a level base so that the steel reinforcement cage can be constructed.
(3) Where the raft is not cast directly against the ground, formwork may be
     required to contain any concrete up-stands.
(4) Once the reinforcement is correctly spaced, and tied together in position,
     the concrete can be poured, vibrated and levelled.
(5) A waterproof membrane can be positioned either underneath the struc-
     tural concrete or on top beneath the insulation. Some architects choose to
     position the damp proof membrane (dpm) on top of the insulation and
     beneath the finish screed. Traditionally the damp proof membrane (dpm)
     was placed on top of the blinding; it is now more common for the dpm to sit
     on top of the insulation (providing the insulation is impermeable). When
     the dpm is positioned above the insulation it not only prevents groundwa-
     ter penetration but also reduces the possibility of interstitial condensation
     forming.
(6) Rigid insulation boards are placed on top of the structural concrete.
(7) Finally a 40 mm sand/cement screed finish is spread and levelled on top
     of the raft.

When the reinforced concrete raft has dried and developed sufficient strength
the walls are raised as illustrated in Figure 3.22. The concrete raft is usually at
least 150 mm thick.

A 40–50 mm sand/cement screed provides the finished floor surface. Edge insulation is used to prevent cold bridging.

Damp proof membrane covers the whole area of the foundation; all joints should be properly sealed (taped).

Rigid insulation board (impermeable) is placed on top of the structural concrete.

Once the reinforcement and any necessary formwork is in place the concrete is poured.

Using steel or concrete spacers, the main reinforcement is correctly positioned ready for incorporation within the concrete slab.

Thin (40–50 mm) layer of concrete is spread over the ground providing a level platform for the reinforcement cage to be constructed.

Elemental U-value for floors is 0.15 W/m²K
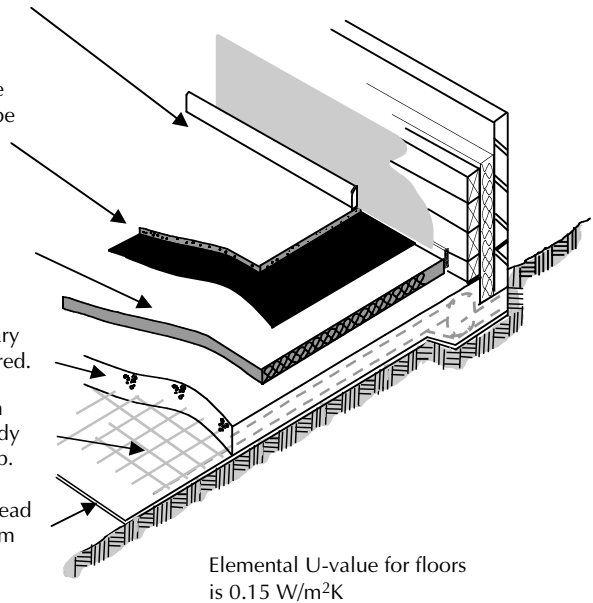
Figure 3.22   Construction of a concrete raft foundation.

A flat slab recommended for building in areas subject to mining subsidence is similar to the flat slab, but cast on a bed of fine granular material 150 mm thick so that the raft is not keyed to the ground and is therefore unaffected by horizontal ground strains. Where the ground has poor compressibility and the loads on the foundations would require a thick, uneconomic flat slab, it is usual to cast the raft as a wide toe raft foundation. The raft is cast with a reinforced concrete, stiffening edge beam from which a reinforced concrete toe extends as a base for the external leaf of a cavity wall as shown in Figures 3.23 and 3.24.

Raft foundation on a sloping site

On sites where the slope of the ground is such that there is an appreciable fall in the surface across the width or length of a building, and a raft foundation is to be used, it is necessary either to cut into the surface or provide additional fill under the building or a combination of both to provide a level base for the raft.

Where the slope is shallow and the design and use of the building allows, a stepped raft may be used down the slope, as illustrated in Figure 3.25. A stepped, wide toe, reinforced concrete raft is formed with the step or steps made at the point of a loadbearing internal wall or at a division wall between
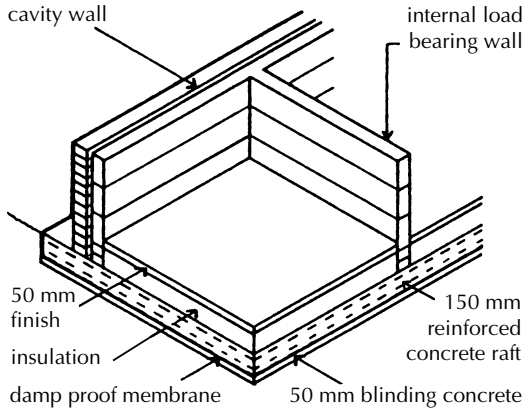
Figure 3.23   Flat slab raft.

compartments. The drains under the raft are to relieve and discharge surface water running down the slope that might otherwise be trapped against steps and promote dampness in the building.

The level raft illustrated in Figure 3.24 is cast on imported granular fill that is spread, consolidated and levelled as a base for the raft. The disadvantage of this is the cost of the additional granular fill and the advantage a level bed of uniform consistency under the raft. As an alternative the system of cut and fill may be used to reduce the volume of imported fill.

Raft foundations are usually formed on ground of soft subsoil or made up ground where the bearing capacity is low or uncertain, to minimise settlement.
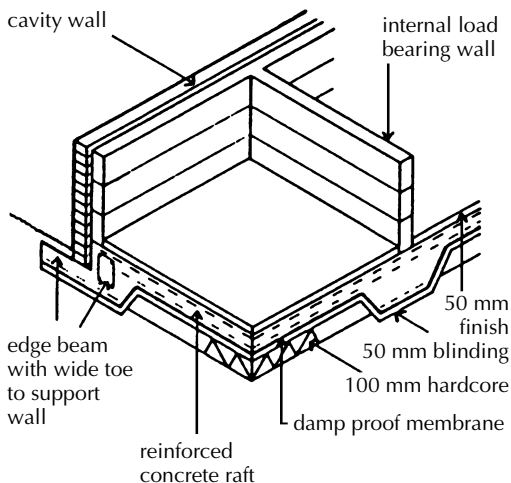
Figure 3.24   Edge beam raft.
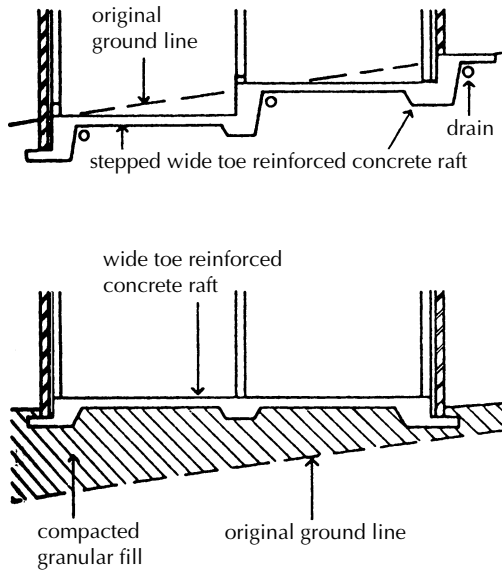
Figure 3.25   Raft on sloping site.

There is some possibility of there being some slight movement of the ground under the building which would fracture drains and other service pipes entering the building through the raft. Service pipes rising through the raft should run through collars, cast in the concrete, which will allow some movement of the raft without fracturing service pipes.

Foundations on sloping sites

The natural surface of ground is rarely level. On sloping sites an initial decision to be made is whether the ground floor is to be above ground at the highest point or partly sunk below ground as illustrated in Figure 3.25. Where the ground floor is to be at or just above ground level at the highest point, it is necessary to import some dry fill material such as hardcore to raise the level of the oversite concrete and floor. This fill will be placed, spread and consolidated up to the external wall once it has been built.

The consolidated fill will impose some horizontal pressure on the wall. To make sure that the stability of the wall is adequate to withstand this lateral pressure it is recommended practice that the thickness of the wall should be at least a quarter of the height of the fill bearing on it as illustrated in Figure 3.27A and B. The thickness of a cavity wall is taken as the combined thickness of the two leaves unless the cavity is filled with concrete when the overall thickness is taken.

To reduce the amount of fill necessary under solid floors on sloping sites a system of cut and fill may be used as illustrated in Figure 3.26. The disadvantage
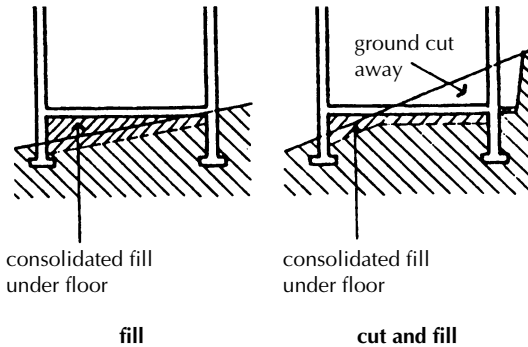
fill   **cut and fill**

Figure 3.26   Fill and cut and fill.

of this arrangement is that the ground floor is below ground level at the highest point and it is necessary to form an excavated dry area to collect and drain surface water that would otherwise run up to the wall and cause problems of dampness. To reduce the depth of excavation and the foundations a stepped foundation is used as illustrated in Figure 3.28.

Figure 3.29 is an illustration of the stepped foundation for a small building on a sloping site where the subsoil is reasonably compact near the surface and will not be affected by volume changes. The foundation is stepped up the slope to minimise excavation and walling below ground. The foundation is stepped
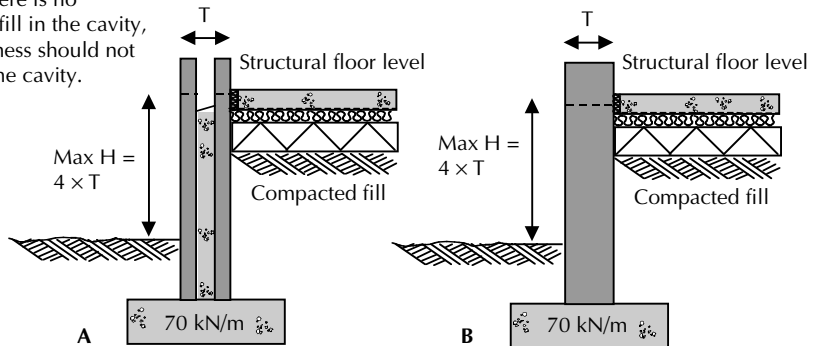
Figure 3.27   Depth of internal hardcore fill and external wall thickness.
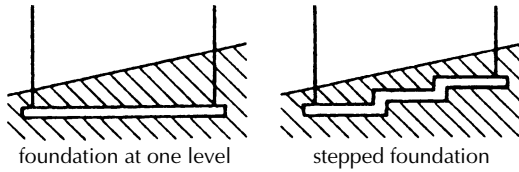
Figure 3.28   Foundation on sloping site.

so that each step is no higher than the thickness of the concrete foundation and the foundation at the higher level overlaps the lower foundation by at least 300 mm.

The loadbearing walls are raised and the foundation trenches around the walls backfilled with selected soil from the excavation. The concrete oversite and solid ground floor may be cast on granular fill no more than 600 mm deep or cast or placed as a suspended reinforced concrete slab. The drains shown at the back of the trench fill are laid to collect and drain water to the sides of the building.

Alternative approaches

With a growing number of alternative approaches to construction inspired by more sustainable architecture and also advances in prefabrication, some alternative approaches to traditional concrete foundations are being used.

Framed building resting on gabions is one such approach, see Figure 3.30. The idea here is that when the building has exceeded its life the structure and the foundation can be easily recovered, recycled and re-used with little loss of resources. Placing the gabions on the ground, rather than in the ground, can also help to reduce the health and safety risks associated with excavating
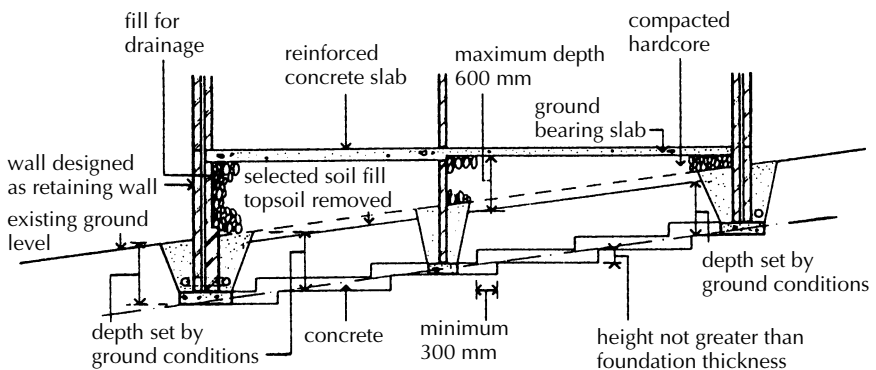
Figure 3.29   Stepped foundation.
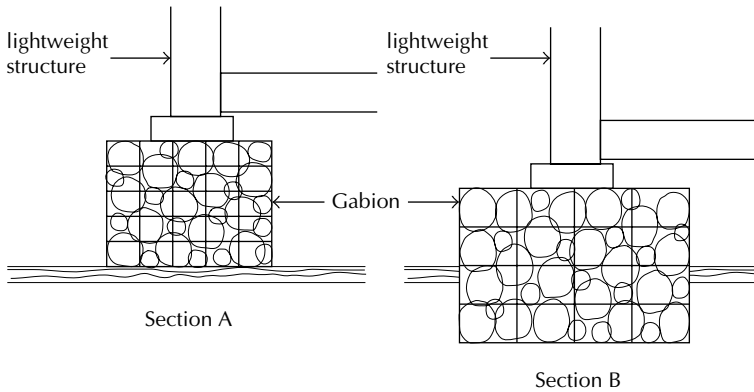
Figure 3.30   Gabion foundation, resting on (A) or in (B) the ground. Gabions can be made locally with recycled stone/materials.

foundations. Uses of such technology tend to be limited to small, often temporary, buildings. Structural calculations will be required to demonstrate compliance with the Building Regulations.

3.5 Site preparation and drainage

Turf and vegetable topsoil should be removed from the ground to be covered by a building, to a depth sufficient to prevent later growth. Tree and bush roots, which might encourage later growth and any pockets of soft compressible material, which might affect the stability of the building, should also be removed. The reasons for removing this vegetable soil are to prevent plants, shrubs or trees from attempting to grow; this would exert pressure on the concrete and crack it. Also once covered over, the vegetation contained in the soil will decay causing voids to form below the concrete. The depth of vegetable topsoil varies and on some sites it may be necessary to remove 300 mm or more vegetable topsoil.

Contaminants

In Approved Document C is a list of contaminants in, or on, ground to be covered by a building, that may be a danger to health or safety. Building sites that may contain contaminants can be identified from planning records or local knowledge of previous uses. Sites that are likely to contain contaminants include:

❑ Asbestos works
❑ Chemical or gas works
❑ Coal carbonisation plants and ancillary byproducts

❏ Industries making or using wood preservatives
❏ Landfill sites
❏ Waste disposals sites
❏ Metal works
❏ Munitions factories
❏ Nuclear installations
❏ Oil stores
❏ Paper printing works
❏ Railway land
❏ Scrap yards
❏ Sewage works
❏ Tanneries

Approved Document C also recommends action necessary if any contaminants are discovered, as described in Table 3.3.

Table 3.3   Possible signs of contaminants and actions.

Signs of possible contaminants	Possible contaminant	Relevant action
No sign of vegetation, or poor or unnatural growth	Metals Metal compounds	None
No sign of vegetation, or poor or unnatural growth	Organic compounds Gases	Removal
Surface colour and contour or materials may be unusual indicating waste	Metals Metal compounds Oily and tarry wastes Asbestos (loose) Other mineral fibres Organic compounds including phenols Combustible material including coal and coke dust Refuse and waste	None Removal, filling or sealing Filling or sealing None Removal or filling Removal or filling Total removal or seek specialist advice
Fumes and odours may indicate organic chemicals at very low concentrations	Flammable explosive and asphyxiating gases including methane and carbon dioxide Corrosive liquids Faecal animal and vegetable matter (biologically active)	Removal Removal, filling or sealing Removal or filling
Drums and containers (whether full or empty)	Various	Removal with all contaminated ground

Adapted from Approved Document C2, Table 2.

Site drainage

Surface water (stormwater) is the term used for rainwater and melted snow that falls on the surface of the ground, including open ground such as fields, paved areas and roofs. Rainwater that falls on paved areas and roofs generally drains to surface water (stormwater) drains and then to soakaways or mains drainage. Paved areas are usually laid to falls to channels and gullies that drain to surface water drains. Rainwater falling on natural open ground will in part lie on the surface of impermeable soils, evaporate to air, run off to streams and rivers and soak into permeable soils as ground water.

Ground water is that water held in soils at and below the water table (which is the depth at which there is free water below the surface). The level of the water table will vary seasonally, being closest to the surface during rainy seasons and deeper during dry seasons when most evaporation to air occurs.

In Approved Document C there is a requirement for 'adequate subsoil drainage', to avoid passage of ground moisture to the inside of a building or to avoid damage to the fabric of the building. Subsoil drainage is also required where the water table can rise to within 0.25 m of the lowest floor, where the water table is high in dry weather and where the site of the building is surrounded by higher ground.

Subsoil drains

Subsoil drains are used to improve the run off of surface water and the drainage of ground water to maintain the water table at some depth below the surface to:

- ❑ Improve the stability of the ground
- ❑ Avoid surface flooding
- ❑ Alleviate or avoid dampness in basements
- ❑ Reduce humidity in the immediate vicinity of buildings

Subsoil drains are either open jointed or jointed, porous or perforated pipes of clayware, concrete, pitch fibre or plastic. The pipes are laid in trenches to follow the fall of the ground, generally with branch drains discharging to a ditch, stream or drain. On impervious subsoils, such as clay, it may be necessary to form a system of drains to improve the run off of surface water and drain subsoil to prevent flooding. Some of the drain systems used are natural, herring bone, grid, fan and moat or cut-off.

Natural system

This system, which is commonly used for field drains, uses the natural contours of the ground to improve run off of surface ground water to spine drains in natural valleys that fall towards ditches or streams. The drains are laid in irregular patterns to follow the natural contours as illustrated in Figure 3.31A.
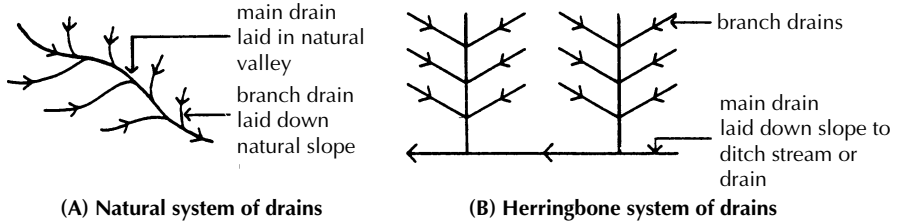
Figure 3.31   (A) Natural system. (B) Herring bone system.

Herring bone system

In this system, illustrated in Figure 3.31B, fairly regular runs of drains connect to spine drains that connect to a ditch or main drain. This system is suited to shallow, mainly one way slopes that fall naturally towards a ditch or main drain and can be laid to a reasonably regular pattern to provide a broad area of drainage.

Grid system

This is an alternative to the herring bone system for draining one way slopes where branch drains are fed by short branches that fall towards a ditch or main drain, as illustrated in Figure 3.32A. This system may be preferred to the herringbone system, where the run off is moderate, because there are fewer drain connections that may become blocked.

Fan system

A fan shaped layout of short branches, illustrated in Figure 3.32B, drains to spine drains that fan towards a soakaway, ditch or drain on narrow sites. A similar system is also used to drain the partially purified outflow from a septic tank to an area of subsoil where further purification will be effected.

On sloping building sites on impervious soil where an existing system of land drains is already laid and where a new system is laid to prevent flooding a moat or cut off system is used around the new building to isolate it from general land drains, as illustrated in Figure 3.33.
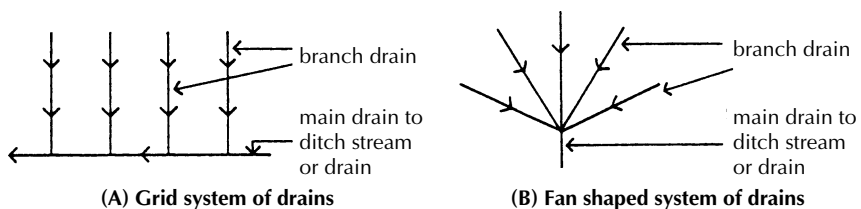
Figure 3.32   (A) Grid system. (B) Fan system.
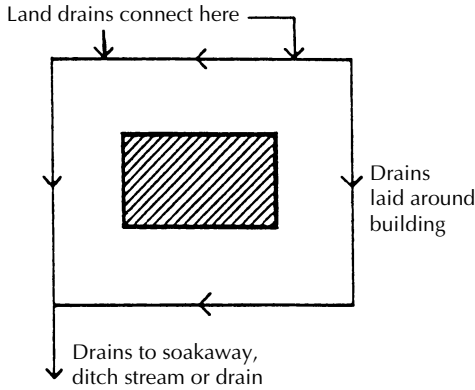
Figure 3.33   Moat or cut off system.

The moat or cut off system of drains is laid some distance from and around the new building to drain the ground between it and the new building and to carry water from the diverted land drains down the slope of the site. The moat drains should be clear of paved areas around the house.

Laying drains

Ground water (land) drains are laid in trenches at depths of 0.6 and 0.9 m in heavy soils and 0.9 to 1.2 m in light soils. The nominal bore of the pipes is usually 75 and 100 mm for main drains and 65 or 75 mm for branches. The drain pipes are laid in the bed of the trench and surrounded with coarse gravel (without any fine gravel). A filtering material (traditionally this was inverted turf or straw) is then placed on top of the gravel; this allows the water to percolate through to the drain without allowing fine material to pass through and block up the surrounding gravel. Excavated material is backfilled into the drain trench up to the natural ground level. The drain trench bottom may be
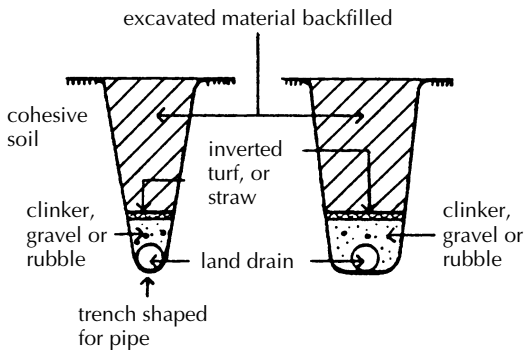
Figure 3.34   Land drains.

shaped to take and contain the pipe or finished with a flat bed as illustrated in Figure 3.34, depending on the nature of the subsoil and convenience in using a shaping tool.

Where drains are laid to collect mainly surface water the trenches are filled with clinker, gravel or broken rubble to drain water either to a drain or without a drain as illustrated in Figure 3.35 in the form known as a French drain. Whichever is used will depend on the anticipated volume of water and the economy of dispensing with drainpipes.

trench filled with clinker, gravel or rubble

trench filled with clinker, gravel or rubble

(A) Surface water drain   **(B) French drain**
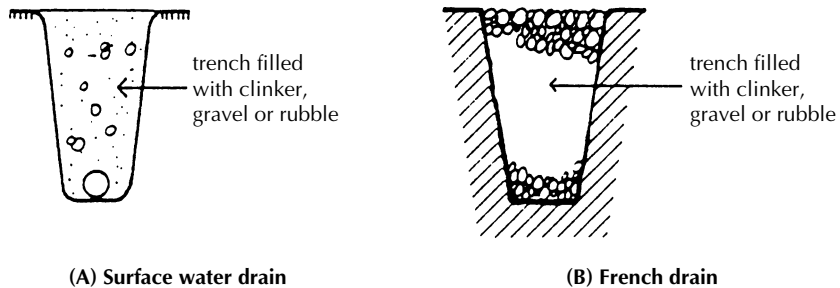
Figure 3.35   (A) Surface water drain. (B) French drain.

Support for foundation trenches

The trenches to be dug for the foundations of walls may be excavated by hand for single small buildings but where, for example, several houses are being built at the same time it is often economical to use mechanical trench diggers. If the trenches are of any significant depth it may be necessary to fix temporary timber supports to stop the sides of the trench from falling in. The nature of the soil being excavated mainly determines the depth of trench for which timber supports to the sides should be used. Working in trenches is dangerous and all health and safety guidance must be complied with in terms of providing adequate support for trenches and hence safe working conditions.

Soft granular soils readily crumble and the sides of trenches in such soil may have to be supported for the full depth of the trench. The sides of trenches in clay soil do not usually require support until a depth of approximately 1.5 m, particularly in dry weather. In wet weather, if the bottom of the trench in clay soil gets filled with water, the water may wash out the clay from the sides at the bottom of the trench and the whole of the sides above may collapse.

The purpose of temporary timbering supports to trenches is to uphold the sides of the excavation as necessary to avoid collapse of the sides, which may endanger the lives of those working in the trench, and to avoid the wasteful labour of constantly clearing falling earth from the trench bottoms.

The material most used for temporary support for the sides of excavations for strip foundations is rough sawn timber. The timbers used are square section
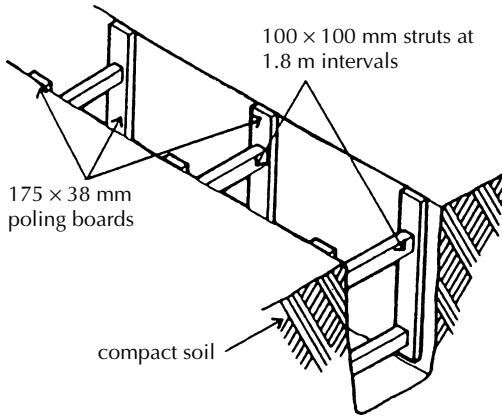
Figure 3.36 Struts and poling boards.

struts, across the width of the trench, supporting open poling boards, close poling boards and walings or poling boards and sheeting.

Whichever system of timbering is used there should be as few struts, that is horizontal members, fixed across the width of the trench as possible as these obstruct ease of working in the trench. Struts should be cut to fit tightly between poling or waling boards and secured in position so that they are not easily knocked out of place. For excavations more than 1.5 m deep in compact clay soils it is generally sufficient to use a comparatively open timbering system as the sides of clay will not readily fall in unless very wet or supporting heavy nearby loads. A system of struts between poling boards spaced at about 1.8 m intervals as illustrated in Figure 3.36 will usually suffice.
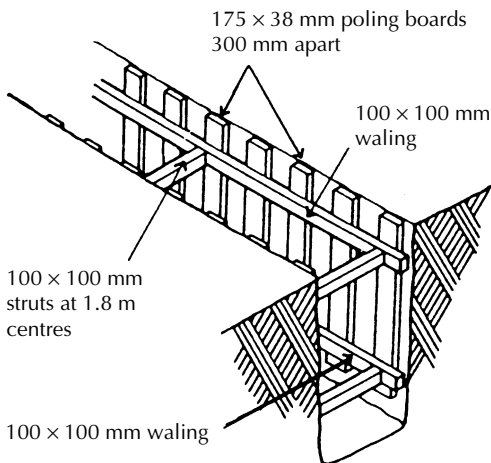
Figure 3.37 Struts, waling and poling boards.
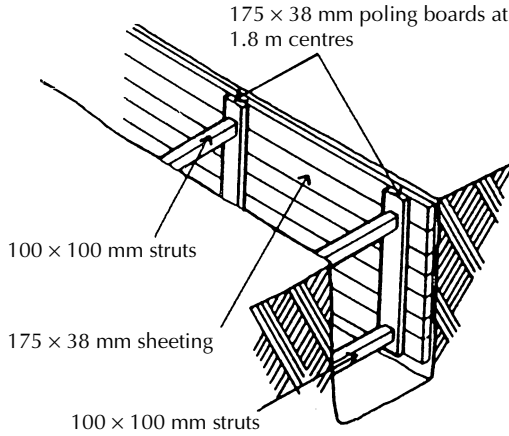
Figure 3.38   Struts, poling boards and sheeting.

Where the soil is soft, such as soft clay or sand, it will be necessary to use more closely spaced poling boards to prevent the sides of the trench between the struts from falling in. To support the poling boards horizontal walings are strutted across the trench, as illustrated in Figure 3.37.
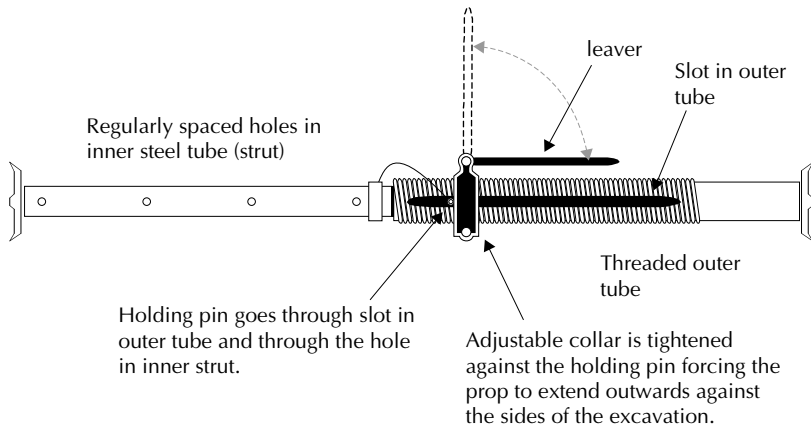
Standard sizes of strut available

Extension in metres	
Closed	**Open**
0.495	0.737
0.705	1.137
1.029	1.740

Figure 3.39   Adjustable steel strut.
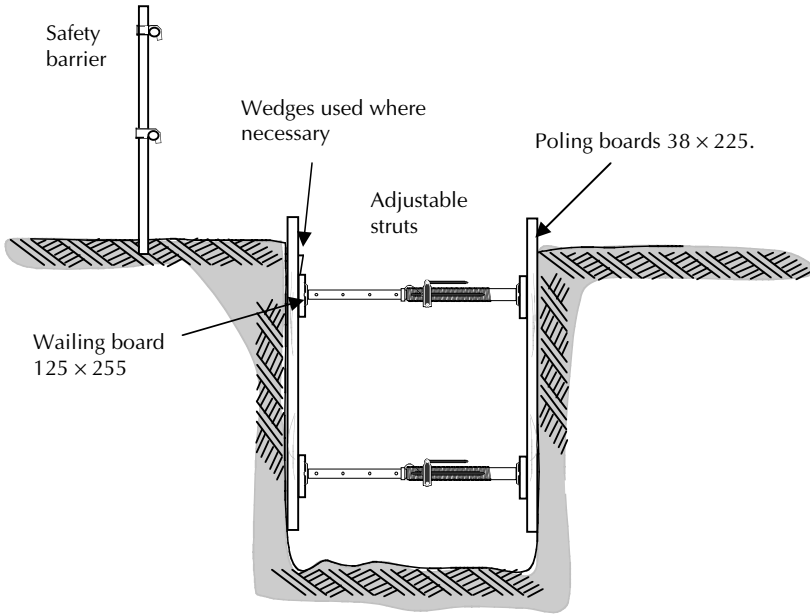
Figure 3.40   Open or closed timbering using adjustable steel strut.

Figure 3.41   Trench box.

The horizontal steel wailing shores are often collapsible. They fold away for easy handling and lock out so that they can be used in the trench.

Steel trench sheets

Struts may be manually adjustable or hydraulic. Hydraulic shores are preferred as they can be pumped out (extended) with a person operating the pump from outside the trench.

Chains hold the wailings securely in place.

Horizontal steel wailings

Figure 3.42   Shoring: horizontal steel wailing.

For trenches in dry granular soil it may be necessary to use sheeting to the whole of the sides of trenches. Rough timber sheeting boards are fixed along the length and up the sides of the trench to which poling boards are strutted, as illustrated in Figure 3.38. The three basic arrangements of timber supports for trenches are indicative of some common systems used and the sizes given are those that might be used.

Although the traditional method of timbering is still used to provide temporary trench support it is more common to use steel shoring systems such as steel walers, adjustable vertical shores, adjustable props, trench sheets and trench boxes as illustrated in Figures 3.39–3.43.

Vertical steel shores fold out so that they can be lowered into the trench without a person entering the unsupported excavation.

Steel trench sheets

Hydraulic pump

Struts may be manually adjustable or hydraulic.

Hydraulic shores are preferred as they can be pumped out (extended) with a person operating the pump from outside the trench.

Vertical steel shores
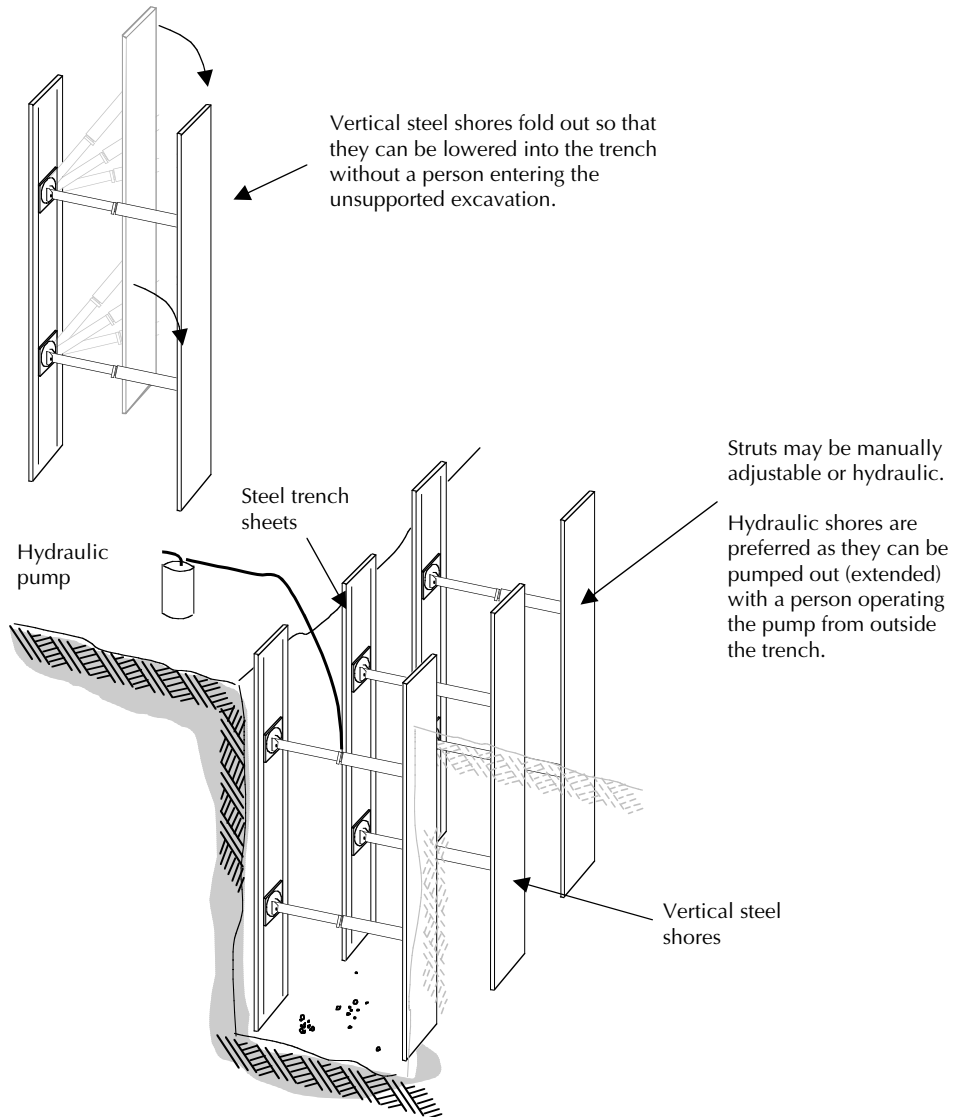
Figure 3.43   Shoring: vertical steel wailing.

If timbering is used for temporary support it is used with adjustable steel struts instead of timber struts. Trench boxes are often used because they provide a safe area in which to work. However, trench boxes cannot be used where services cross the excavation. Because trench support has to be chosen to suit particular site conditions it is common to find a combination of systems in more complex situations.

4 Floors

Concrete and timber are the two materials most used for the construction of ground and upper floors, the choice of one over another determined largely by the span required and the required performance in terms of fire safety and the resistance to the passage of heat and sound. Ground and upper floors constructed of concrete or timber are described in this chapter. Figure 4.1 provides examples of some of the more common types of floor construction.

4.1 Functional requirements

The functional requirements of a floor are:

❑ Strength and stability
❑ Resistance to weather and ground moisture
❑ Durability and freedom from maintenance
❑ Fire safety – resisting spread and passage of fire
❑ Fire safety – providing stable support for occupants to evacuate
❑ Resistance to passage of heat
❑ Resistance to the passage of sound

Strength
The strength of a floor depends on the characteristics of the materials used for the structure of the floor, such as timber, steel or concrete. The floor structure must be strong enough to support safely the dead load of the floor and its finishes, fixtures, partitions and services and the anticipated imposed loads of the occupants and their movable furniture and equipment. BS 6399: Part 1 is the Code of Practice for dead and imposed loads for buildings. Where imposed loads are small, as in single family domestic buildings of not more than three storeys, a timber floor construction is usual. The lightweight timber floor structure is adequate for the small loads over small spans. Precast concrete block and beam flooring offers an economical and quick alternative to timber floors. For larger imposed loads and wider spans a reinforced concrete floor is used, both for strength in support and also for resistance to fire. Approved Document A includes tables of recommended sizes and spacing for softwood timber floor joists of two strength classes, for various dead loads and spans.

Stability
A floor is designed and constructed to serve as a horizontal surface to support people and their furniture, equipment or machinery. The floor should have
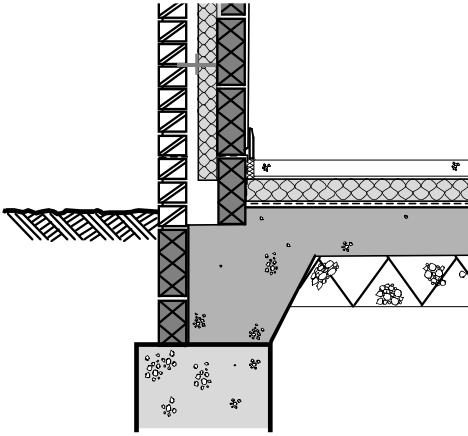
A   Screed finish floor resting on raft foundation
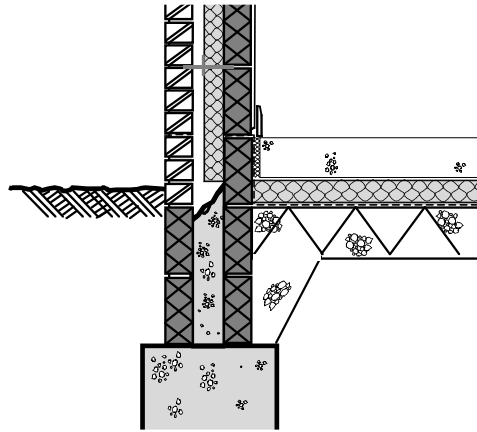
B   Ground bearing floor with insulation below the concrete slab
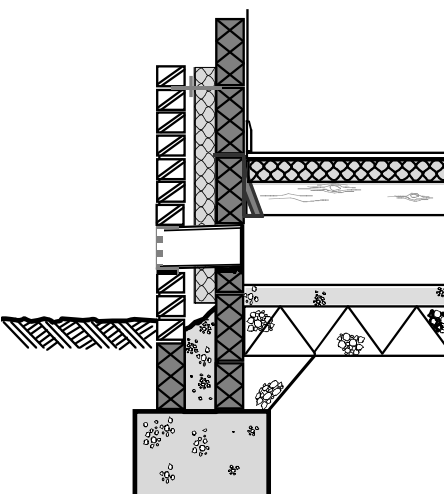
C   Suspended timber ground floor
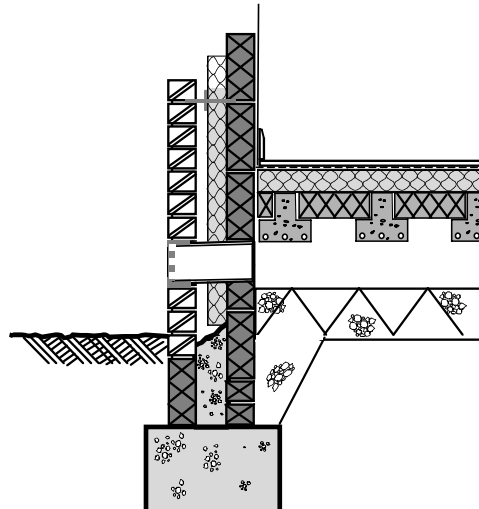
D   Suspended precast concrete block and beam ground floor

Figure 4.1   Ground floor types.

adequate stiffness to remain stable and horizontal under the dead load of the floor structure and such partitions and other fixtures it supports and the anticipated static and live loads it is designed to support. The floor structure should also support and accommodate services either in its depth, or below or above the floor, without affecting its stability.

Solid ground and basement floors are often built off the ground from which they derive support. The stability of such floors depends, therefore, on the characteristics of the concrete under them. Upper or suspended floors are supported by walls or beams and should have adequate stiffness to minimise deflection under load. Under load a floor will deflect and bend and this deflection or bending should be limited to avoid cracking of rigid finishes such as plasterboard, which are attached to the ceiling directly below the floor.

Resistance to weather and ground moisture
The requirements of the Building Regulations for the resistance of the passage of moisture through ground floors to the inside of buildings are described below.

Durability and freedom from maintenance
All floors should be durable for the expected life of the building and require little maintenance or repair. The durability and freedom from maintenance of floor finishes will depend on the nature of the materials used and the wear to which they are subject.

Fire safety
Suspended upper floors should be so constructed as to provide resistance to fire for a period adequate for the escape of the occupants from the building. The notional periods of resistance to fire, from $\frac{1}{2}$ to 4 hours, depending on the size and use of the building, are set out in the Building Regulations.

Resistance to the passage of heat
A floor should provide resistance to transfer of heat where there is normally a significant air temperature difference on the opposite sides of the floor; this would include any building which was heated, but would not include some external buildings, such as garages.

Resistance to the passage of sound
Upper floors that separate dwellings (party floors), or separate noisy from quiet activities, should act as a barrier to the transmission of sound. The comparatively low mass of a timber floor will transmit airborne sound more readily than a high mass concrete floor, so that party floors between dwellings, for example, are generally constructed of concrete. The hard surfaces of the floor and ceiling of both timber and concrete floors will not appreciably absorb airborne sound, which will be reflected. The sound absorption of a floor can be improved by introducing a soft absorbent material such as carpet or felt. Absorbent tiles and finishes can be used on walls and ceilings to reduce echo effects caused by sound reflecting and bouncing back off hard surfaces.

When upgrading existing buildings, sound insulation can be improved by filling between timber joists and sealing voids, or by constructing a floating floor, or suspended floor, both of which introduce breaks between the floor

surface and the structural floor. Where cavities exist between the floor surface and the structural floor, sound insulating materials can be introduced to add further sound reductions. Floating floors prevents the impact sound from foot traffic transferring to the main structure. Specially designed acoustic based resilient floor coverings that reduce impact sound are also available.

4.2 Ground supported concrete slab

A typical concrete ground supported slab is shown in Figure 4.2. It is general practice first to build the external and internal loadbearing walls from the concrete foundation up to the level of the dpc. The hardcore bed and the concrete slab are then spread and levelled within the area created by the walls. If the hardcore is spread and consolidated over the whole area of the ground floor, into and around excavations used to construct foundations and where soft ground has been removed, there should be very little settlement of the ground that supports the floor slab. The hardcore should be thoroughly consolidated using a vibrating plate or roller. Settlement cracking in ground floor slabs is often due to inadequate hardcore bed, poor filling of excavation for trenches or ground movement due to moisture changes (swelling or shrinkage of clay
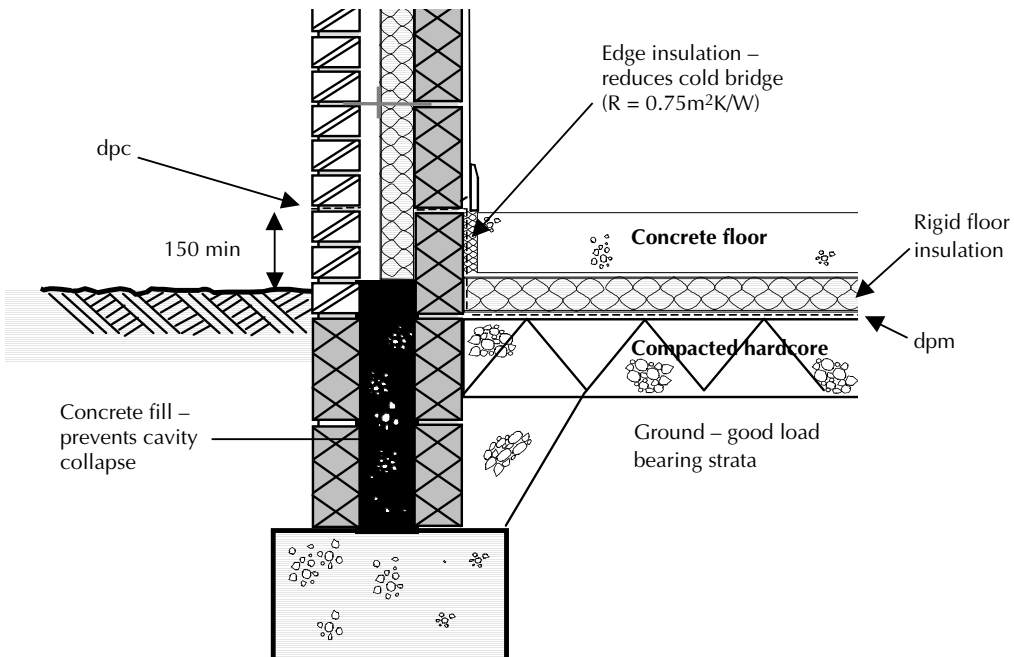
Figure 4.2   Concrete ground bearing floor construction.

soils). Where appreciable settlement is anticipated it is best to reinforce the slab and build it into walls as a suspended reinforced concrete slab. The gap below the floor will allow clay soils to swell and contract without causing damage to the structural floor.

Hardcore

Hardcore is the name given to the infill of materials such as crushed and graded bricks, stone or concrete, which are hard and do not readily absorb water or deteriorate. Hardcore should be spread until it is level, then compacted using a mechanical vibrating plate or roller. The hardcore provides a stable bed for the concrete slab; this hardcore bed is usually 100 to 300 mm deep. The materials used for hardcore should be chemically inert, not appreciably affected by water and be free from water-soluble sulphates. A method of testing materials for soluble sulphate is described in *Building Research Station (BRS) Digest 174*. The materials used for hardcore are:

❑ Brick or tile rubble. Clean, hard broken brick or tile crushed and graded. Bricks should be free of plaster and wood. On wet sites the bricks should not contain appreciable amounts of soluble sulphate.
❑ Concrete rubble. Clean, broken, well graded concrete is a good material for hardcore. The concrete should be free from plaster, wood or other building materials.
❑ Gravel and crushed hard rock. Clean, well graded gravel or crushed hard rock are both excellent, but somewhat expensive materials for hardcore.
❑ Chalk. Broken chalk is a good material for hardcore providing it is protected from expansion due to frost. Once the site concrete is laid it is unlikely to be affected by frost.
❑ Road planings. When roads are resurfaced the top of the road is planed off. The planings provide a very good strong hardcore, which binds together when compacted.

Blinding layer

It was common for hardcore to have a blinding layer of dry concrete or sand, 50 mm deep, placed on it before the concrete was laid. The purpose of this was to prevent the wet concrete running down between the lumps of broken brick or stone, and to form a smooth bed for the damp-proof membrane. Now that hardcores are well graded with a mixture of fine and course material, when the hardcore is adequately compacted the surface finish is relatively smooth and level, thus a blinding layer is unnecessary. Where a reinforced cage is to be used within the concrete slab it is useful to have a level surface from which to work. Thus blinding may be used so that the reinforcement cage can be easily

constructed on the level surface, and properly spaced and positioned off the concrete blinding.

Damp-proof membrane (dpm)

A requirement of the Building Regulations is that floors shall adequately resist the passage of moisture to the inside of the building. As concrete is permeable to moisture, it is necessary to use a damp-proof membrane under, in or on top of ground supported concrete floor slabs as an effective barrier to moisture rising from the ground. The membrane should be continuous with the damp-proof course in walls to prevent moisture rising between the edges of the concrete slab and walls. A damp-proof membrane should be impermeable to water in either liquid or vapour form and be tough enough to withstand possible damage during the laying of screeds, concrete or floor finishes. The position of the dpm will vary in accordance with the proposed method of construction.

Damp-proof membrane below concrete

The membrane is spread on a blinding layer or directly onto the hardcore if well graded and smooth. The edges of the membrane are turned up the faces of the external and internal walls so that it may unite and overlap the damp proof course (dpc) in the wall. The membrane should be spread with some care to ensure that it is not punctured and that the edge upstands are kept in place as the concrete is subsequently laid.

The advantage of a damp-proof membrane under the concrete is that it will be protected from damage during subsequent building operations. The concrete remains dry and protected from impurities. However, unless the concrete is likely to suffer chemical attack, the dampness caused by ground water is not a cause for concern and the dpm can just as easily be placed on top of the concrete. When rigid impermeable insulation is used the dpm should be placed on the warm side (internal side) of the insulation, reducing the possibility of interstitial condensation (Figure 4.3A). Although concrete does have a level of natural resistance to the passage of moisture poor work-manship may mean that water vapour can penetrate the structure. Where under floor heating is used the membrane should be under the concrete (Figure 4.3B).

If the insulation is placed on top of the concrete and a timber finish is applied to the surface a vapour control layer must be used (Figure 4.3C). If a vapour barrier is not used, warm moist air will penetrate through the timber finish to the cold side of the insulation and form condensation on top of the dpm. If the insulation is permeable then the dpm must go below the insulation and a vapour barrier may be used on top of the insulation.

Without a vapour barrier it is possible that interstitial condensation may form on top of the damp proof membrane.

Warm internal

Cold ground
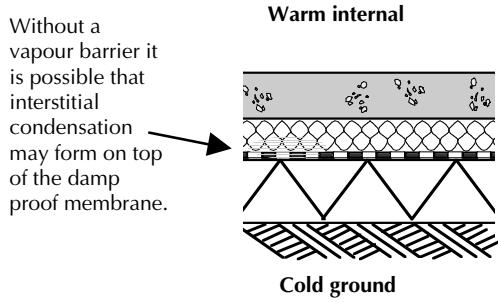
A   dpm placed below the rigid impermeable insulation

Concrete floor slab

dpm

Insulation

Hardcore

Formation level (ground)

Warm internal

Cold ground
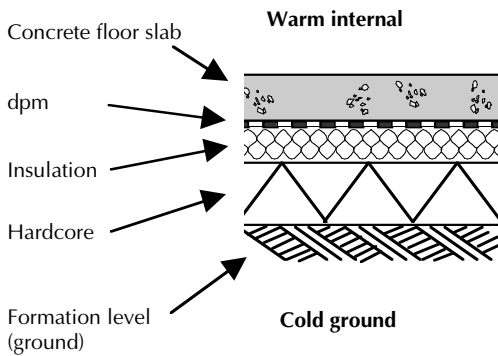
B   dpm placed above the rigid impermeable insulation

Timber floor finish

Vapour control layer

Rigid insulation

Concrete floor slab

dpm

Hardcore

Formation level (ground)

Warm internal

Cold ground
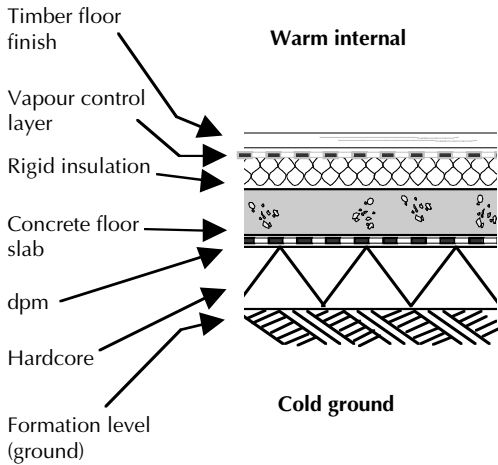
C   Insulation above concrete with timber finish dpm and vapour control layer required

Figure 4.3   A, B & C Sections showing the alternative position of the dpm in solid concrete ground floors.

Sand–cement screed with nominal reinforcement

dpm

Insulation

Concrete floor slab

Hardcore

Formation level (ground)

**dpm and insulation sandwiched
between the screed and concrete**
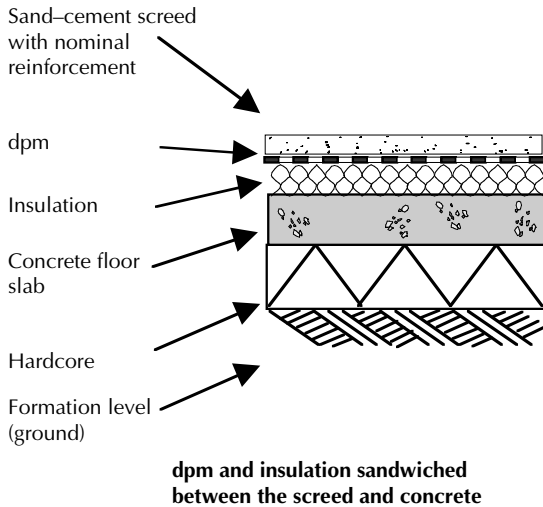
Figure 4.4   Position of dpm in solid ground floors.

Surface damp-proof membrane

Floor finishes such as pitch mastic and mastic asphalt that are impermeable to water can serve as a combined damp-proof membrane and floor finish. These floor finishes should be laid to overlap the damp-proof course in the wall to seal the joint between the concrete and the wall. Where hot soft bitumen or coal tar pitch are used as an adhesive for wood block floor finishes, the continuous layer of the impervious adhesive can serve as a waterproof membrane.

Damp-proof membrane below a floor screed

An alternative method is to place the dpm between the floor screed and the thermal insulation, as illustrated in Figure 4.4. At the junction of wall and floor the membrane should overlap the damp-proof course in the wall.

Materials used for the dpm

The materials used as damp-proof membrane must be impermeable to water both in liquid and vapour form and sufficiently robust to withstand damage by later building operations.

Polythene and polyethylene sheet

Polythene or polyethylene sheet is commonly used as a damp-proof membrane with oversite concrete for all but severe conditions of dampness. It is recommended that the sheet should be at least 0.25 mm thick (1200 gauge). The sheet is supplied in rolls 4 m wide by 25 m long. The sheets are spread over the blinding and lapped 150 mm at joints and continued across surrounding walls, under the dpc for the thickness of the wall. Where site conditions are
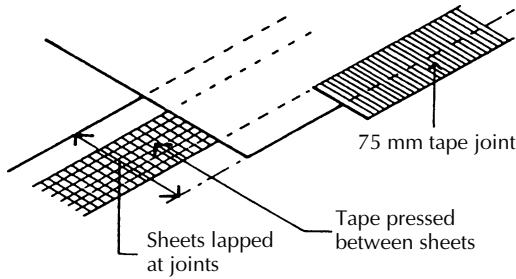
Figure 4.5   Jointing laps in polythene sheet.

reasonably dry and clean, the overlap joints between the sheets are sealed with mastic or mastic tape between the overlapping sheets and the joint completed with a polythene jointing tape as illustrated in Figure 4.5.

For this lapped joint to be successful the sheets must be dry and clean or the jointing tape will not adhere to the surface of the sheets. Where site conditions are too wet to use mastic and tape, the joint is made by welting the overlapping sheets with a double welted fold as illustrated in Figure 4.6, and this fold is kept in place by weighing it down with bricks or securing it with tape until the screed or concrete has been placed. The sheet should be used so that there are only joints one way as it is impractical to form a welt at junctions of joints.

Where the level of the damp-proof membrane is below that of the dpc in walls, it is necessary to turn it up against walls so that it can overlap the dpc or be turned over as dpc as illustrated in Figure 4.7. To keep the sheet in place as an upstand to walls it is necessary to keep it in place with bricks or blocks laid on the sheet against walls until the concrete has been placed and the bricks or blocks removed as the concrete is run up the wall. At the internal angle of walls a cut is made in the upstand sheet to facilitate making an overlap of sheet at corners.
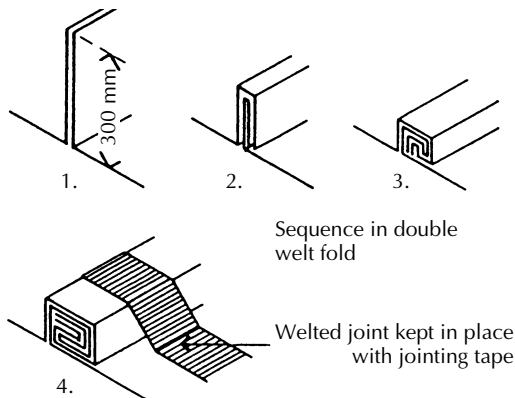
Figure 4.6   Double welted fold joint in polythene sheet.
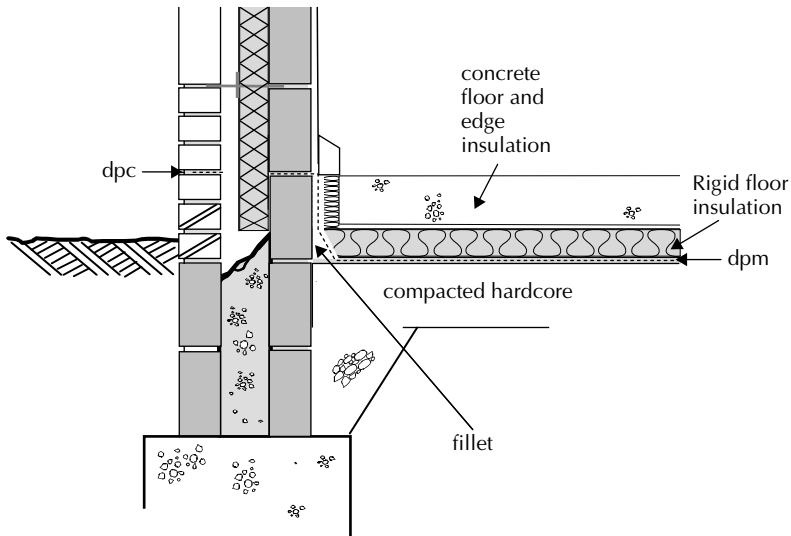
Figure 4.7   Damp-proof membrane turn up.

Hot pitch or bitumen

A continuous layer of hot applied coal-tar pitch or soft bitumen is poured on the surface and spread to a thickness of not less than 3 mm. In dry weather a concrete binding layer is ready for the membrane 3 days after placing. The surface of the concrete should be brushed to remove dust and primed with a solution of coal-tar pitch or bitumen solution or emulsion. Properly applied pitch or bitumen layers serve as an effective damp-proof membrane both horizontally and spread up inside wall faces to unite with dpcs in walls.

Bitumen solution, bitumen/rubber emulsion or tar/rubber emulsion

These cold applied solutions are brushed on to the surface of concrete in three coats to a finished thickness of not less than 2.5 mm, allowing each coat to harden before the next is applied.

Bitumen sheet

Sheets of bitumen with hessian, fibre or mineral fibre base are spread on the concrete oversite or on a blinding of stiff concrete below the concrete, in a single layer with the joints between adjacent sheets lapped 75 mm. The joints are then sealed with a gas torch, which melts the bitumen in the overlap of the sheets sufficient to bond them together. Alternatively the lap is made with hot bitumen spread between the overlap of the sheets, which are then pressed together to make a damp-proof joint. The bonded sheets may be carried across adjacent walls as a dpc, or up against the walls and then across as dpc where the membrane and dpc are at different levels.

The polythene or polyester film and self-adhesive rubber/bitumen compound sheets, described in Volume 2 under 'Tanking', can also be used as damp-proof membranes, with the purpose cut, shaped cloaks and gussets for upstand edges and angles. This type of membrane is particularly useful where the membrane is below the level of the dpc in walls. Bitumen sheets, which may be damaged on building sites, should be covered by the screed or concrete slab as soon as possible to avoid damage.

Mastic asphalt or pitch mastic
These materials are spread hot and finished to a thickness of at least 12.5 mm. This expensive damp-proof membrane is used where there is appreciable water pressure under the floor and as 'tanking' to basements as described in Volume 2.

4.3 Suspended concrete floor slabs

Suspended concrete slabs or block and beam floors are used where the ground:

❑ Slopes
❑ Has poor or uncertain bearing capacity
❑ Is liable to volume change (swells and shrinks)

In such situations it may be wise to form the ground floor as a suspended reinforced concrete slab, or to use a block and beam floor, supported by external and internal loadbearing walls, which are independent of the ground. Suspended concrete floors can be constructed using:

❑ Pre-cast reinforced concrete planks or slabs
❑ Block and beam floor systems or
❑ Insitu reinforced concrete slabs

All of these are described later for upper floors.

T beam method
It is common practice to construct raised concrete floors using the concrete block and inverted T beam method (see Photograph 4.1; also see 4.3 Reinforced concrete upper floors). Brick or concrete block sleeper walls are built off the ground slab to support the concrete 'T' beams. The precast inverted 'T' beams are located on the perimeter walls and internal sleeper walls; concrete infill blocks are then inserted between the beams. Spacing between sleeper walls is dictated by an economical span for the inverted 'T' beams. A concrete topping or screed is spread and levelled over the precast concrete units. Where there is a likelihood of an accumulation of gas building up in the space below the floor, the space should be at least 150 mm clear and cross ventilation should be provided.

Precast reinforced concrete 'T' beams with concrete infill blocks slotted between the beams.

Timber deck (T&G, chipboard, MDF). dpm also acts as vapour barrier. Rigid insulation provides thermal resistance.

Void – Cavity

A   Suspended concrete beam and block ground floor

Screed finish 65+ mm

dpm acts as vapour barrier and also prevents screed getting between gaps in rigid insulation

Concrete infill blocks provide strong and rigid floor. If lightweight, blocks provide extra insulation.

Void – Cavity

50 mm oversite concrete laid on 100 mm compacted hardcore

B   Concrete beam and block ground floor with screed finish

The dpm placed on top of the rigid polystyrene blocks acts as a vapour barrier preventing interstitial condensation forming on the cold concrete beams

Chipboard or MDF is laid across the timber battens which are fixed to the T beams.

Void – Cavity

Hardcore

C   Suspended concrete beam and rigid insulation infill

The dpm placed on top of the rigid polystyrene blocks acts as a vapour barrier preventing interstitial condensation forming on the cold concrete beams

Lightly reinforced structural concrete topping

Void – Cavity

Hardcore

D   Suspended concrete beam and rigid insulation infill with structural concrete topping

Figure 4.8   Alternative arrangements for block and beam floors.

Solid reinforced concrete beams usually shaped like an inverted T in section are precast to the required length. The depth of the beams is from 130 to 250 mm. The beams are made in lengths of up to 6 m. The 'T' beams are reinforced with mild steel reinforcing bars to provide adequate support for the dead weight of the floor and anticipated dead and live loads.

Precast lightweight concrete infill blocks are made to fit between and bear on the 'T' beams. Some of the blocks are hollow (for lightness), although it is becoming more common to use solid blocks. It is possible to use rigid insulation between the beams, instead of concrete blocks (Figure 4.8 and Photograph 4.2).

Floor surface

The term floor finish is generally used to describe the material or materials that are applied to a floor surface as a finished surface, such as tiles (see Chapter 10).

Concrete blocks

Blocks simply placed in position between the precast concrete 'T' beams.

Reinforced concrete 'T' beams

with the block and beams in position the floor is ready for the insulation and can be prepared to receive a concrete topping.

Block work will provide edge support for the concrete.
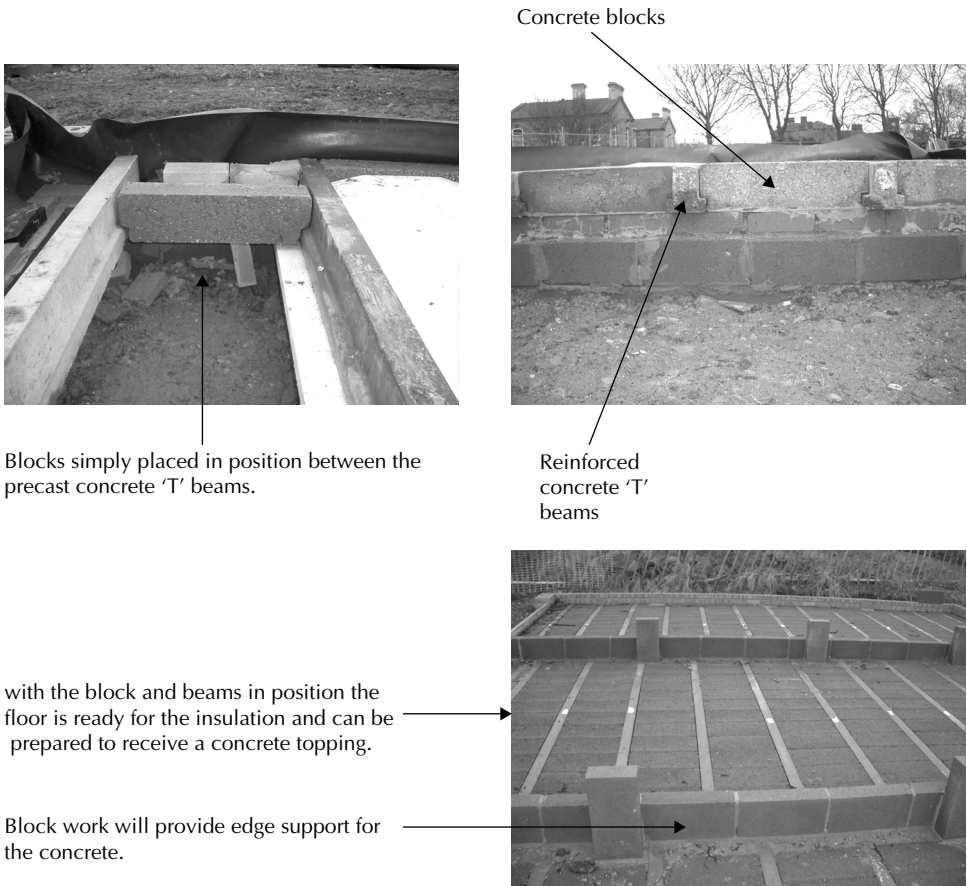
Photograph 4.1   Block and beam floors.
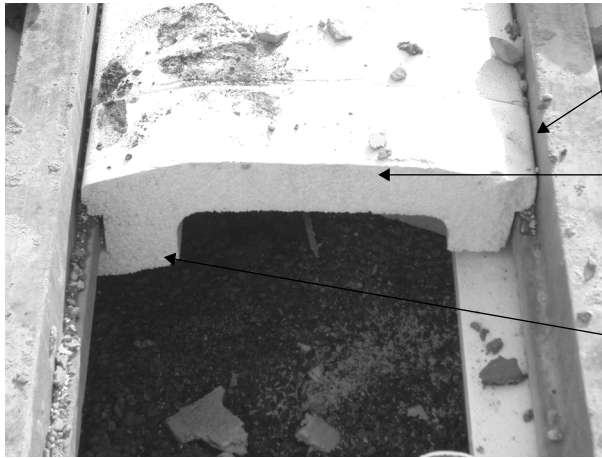
Precast concrete beams rest on internal blockwork skin

Rigid insulation infill panel is supported by the concrete beams

The insulation panel is specially designed so that it laps under the concrete beam preventing a cold bridge
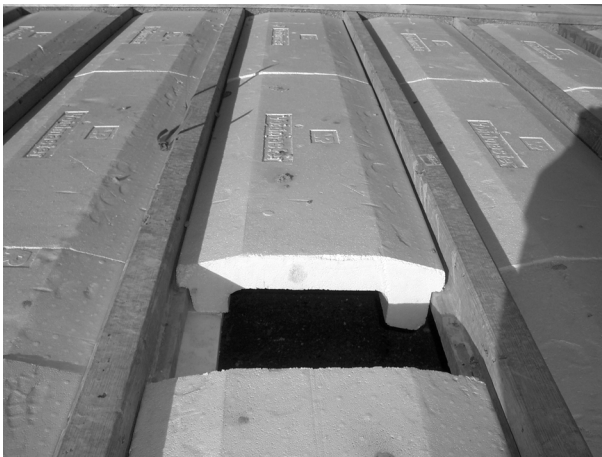
Once the concrete 'T' beams are in position the lightweight insulation panels are quickly positioned

Once the concrete beams and insulation panels are in position a layer of concrete can then be applied over the whole floor.

Photograph 4.2   Precast concrete 'T' beams and insulation infill panels.
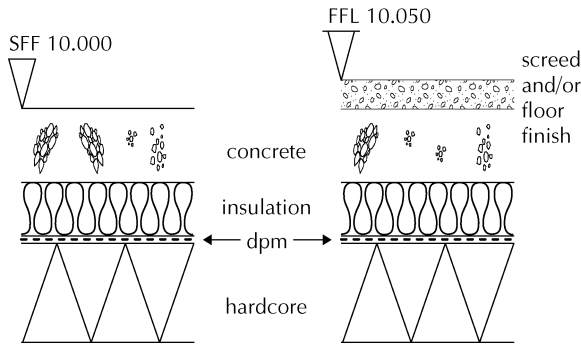
Figure 4.9   Structural and finished floor levels.

It is important to distinguish clearly between the level of the structural floor finish (SFF) and the finished floor finish (FFL) to avoid confusion on site (see Figure 4.9).

For sheds, workshops, stores and garages, the structural floor finish of the concrete is sometimes used as the finished floor surface to save the cost of an applied floor finish. Unless finished and sealed correctly, concrete floors have poor resistance to wear and in a short time the surface of the concrete 'dusts'. Being a coarse grained material, concrete cannot be washed clean, and if it becomes stained the stains are permanent.

Extensive areas of concrete floor may be levelled and finished by power floating. Concrete floors provide a satisfactory base for the thicker floor finishes such as mastic asphalt, tiles and wood blocks. For the thin finishes such as plastic, linoleum, rubber sheet and tile, the more precisely level, smooth surface of a screeded base is necessary. However, with the increasing precision of concrete laying machines that are guided and levelled by lasers, floors can be produced that are level within a tolerance of ±1.5 mm. The use of concrete laying machines is restricted by access through the building to the floor area and obstructions within the structure.

Floor screeds

The purpose of a floor screed is to provide a level surface to which a floor finish can be applied. The word screed is used to describe the wet sand–cement mix that is first laid across the length and width of the floor. If screed finishes are to be used over large areas it may be necessary to lay the screed in strips or bays. The screed strips or bays are carefully levelled in both directions to set out a precise level finish. The main bulk of the mix (which is semi-dry) is then spread and levelled between the screeds.

Generally screed mixes have just sufficient water for hydration; the screed mixes do not have the wet workable properties of concrete typically used in

floor construction. Too much water will cause the screen to slump. The screed has a composition such that when it is formed to the level required it remains in position. This is not the same for self levelling screeds or compounds which are much more fluid in composition and are poured in thin layers on to the floor, lightly floated and then left to level out.

The thickness of the screed and the mix of cement and sand depend on the surface on which the screed is laid. The cement-rich mix used in a screed will shrink as it dries, thus the thinner the screed the more rapidly it will dry and the more it will shrink and crack.

On the majority of building sites the concrete ground and upper floors are cast and roughly levelled as a working platform for subsequent building operations. To avoid damage to screeded surfaces that will serve as a finished floor surface or as a level base or substrate to applied floor finishes it is usual to lay a screed after the concrete floor has dried and hardened.

Bonded screeds

Where it is practical to lay a screed on a concrete base within 3 hours of placing the concrete it will bond strongly to the concrete. The screed will also dry slowly with the concrete so that drying shrinkage and cracking of the screed relative to that of the concrete will be minimised. For this monolithic construction of screed a thickness of 12 mm of screed will suffice (Figure 4.10).

Semi bonded screeds

A screed laid on a concrete base that has set and hardened should be at least 40 mm thick. To provide a good bond between the screed and the concrete, the surface of the concrete should be hacked by mechanical means, cleaned and dampened and then covered by a thin grout, or wet mix, of water and cement

12+ mm thick screed forms chemical bonds with the structural concrete floor

A chemical retarder can be sprayed on the surface of the concrete. The retarder prolongs the set of the structural concrete and increases the bond to the screed.

12 mm screed

150+ mm structural floor

Structural concrete laid and allowed to mature to initial set (3 hours)
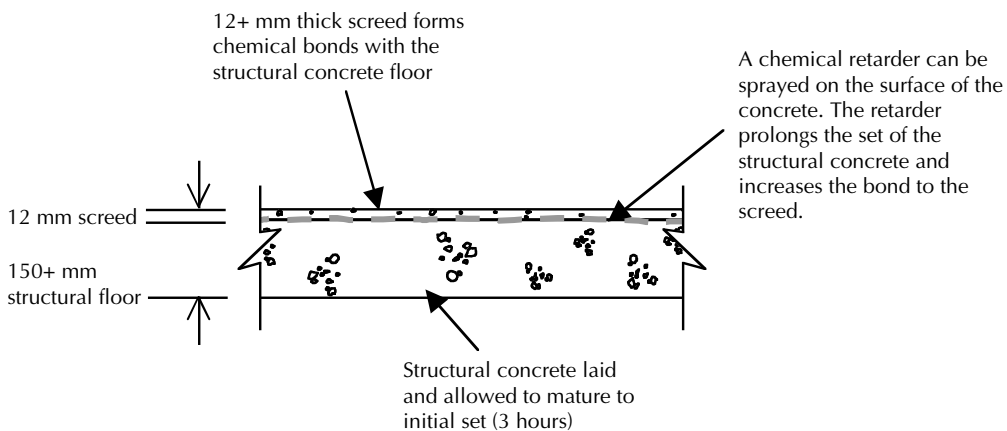
Figure 4.10   Bonded screed.

40+ mm screed. Mechanically
bonds to screed – interlocks into
concrete pores (not chemically
bonded)

Surface of concrete should be
mechanically hacked or
scabbled. The irregular and
porous features of the
structural concrete will allow
the screed to form a
mechanical bond – meshes
with the concrete

40 mm screed

150+ mm
structural floor

Structural concrete laid and
allowed to set

Figure 4.11   Semi-bonded screed.

before the screed is laid. With a good bond to the concrete base a separate screed
at least 40 mm thick will dry sufficiently slowly to avoid serious shrinkage
cracking (Figure 4.11).

Independent or unbonded screeds
Where a screed is laid on an impermeable dpm there will be no bond between
the screed and the concrete base so that drying shrinkage of the screed is
unrestrained. So that the screed does not dry too rapidly and suffer shrinkage
cracking, the screed in this unbonded construction should be at least 50 mm
thick, reinforced with light mesh (Figure 4.12).

50+ mm screed. No bond – dpm
forms slip membrane

dpm allows screed to slip
over the concrete as it
shrinks. Slip membrane
prevents cracking

50 mm screed

150+ mm
structural floor

Structural concrete laid
and allowed to set
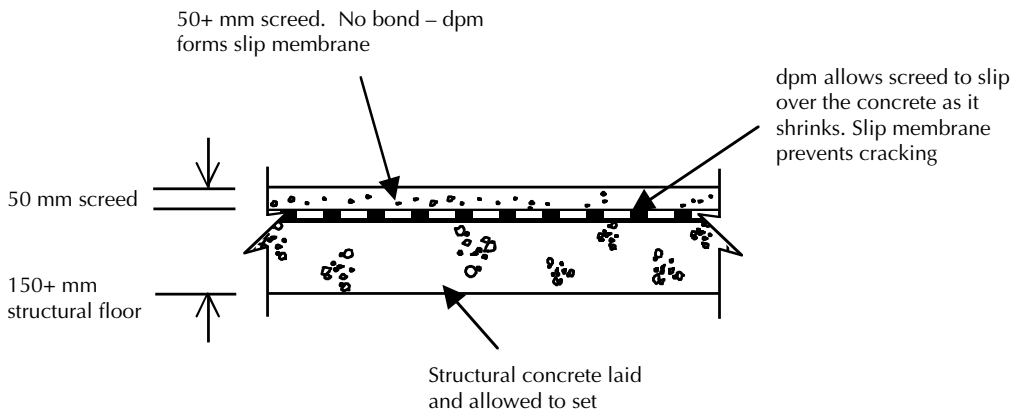
Figure 4.12   Unbonded screed.

60–75+ mm screed. No bond, floats on rigid insulation board.

With the dpm on the warm side of the insulation, warm moist air is prevented from passing to the cold side of the insulation and forming interstitial condensation.

60–75 mm screed

150+ mm structural floor

Insulation is used for thermal properties, but will also improve sound insulation as it provides a break in the structure.

Structural concrete laid and allowed to set

Figure 4.13   Floating floor – screed.

Floating floor – screed
A screed laid on a layer of compressible thermal or sound insulating material should be at least 65 mm thick for domestic buildings and 75 mm for other buildings, if this floating construction is not to crack due to drying shrinkage and the deflection under loads on the floor (Figure 4.13).

For screeds up to 40 mm thick, a mix of cement and clean sand in the proportions by weight of 1:3 to 1:4$\frac{1}{2}$ is used. The lower the proportion of cement to sand the less the drying shrinkage. For screeds over 40 mm thick a mix of fine concrete is often used in the proportions of 1:1$\frac{1}{2}$:3 of cement, fine aggregate and coarse aggregate with a maximum of 10 mm for the coarse aggregate.

Screed should be mixed with just sufficient water for workability. The material is spread over the surface of the base to the required level and then it is finished with a plastic or steel float. The screed should be cured, that is allowed to dry out slowly over the course of several days. Curing prevents the water needed for hydration evaporating out of the screed. The water within the wet concrete mix can be held in place by covering the screed with polythene sheeting, damp hessian, or a liquid chemical curing agent (which is sprayed on to the surface of the screed). Premixed cement screed materials are available and can be delivered to site with polymer or steel fibre for reinforcement.

4.4 Suspended timber ground floors

A suspended or raised timber ground floor is constructed as a timber platform of boards nailed across timber joists bearing on $\frac{1}{2}$ brick (B) thick walls raised directly off the packed earth, brick rubble or site concrete, as illustrated in Figure 4.14. The raised timber floor is formed inside the external walls and
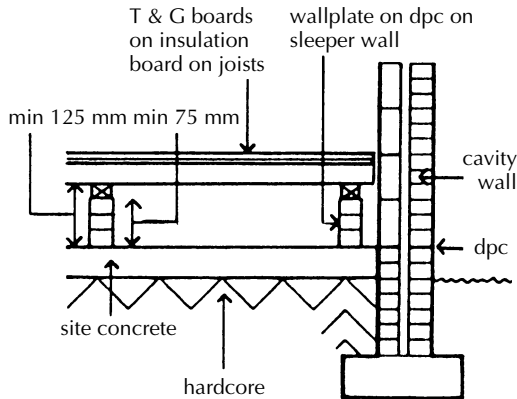
Figure 4.14   Suspended timber floor.

internal brickwork partitions, and is supported on brick sleeper walls. Sleeper walls are $\frac{1}{2}$ B thick and built directly off the site concrete up to 1.8 m apart. These sleeper walls are generally built at least three courses of bricks high and sometimes as much as 600 mm high. The walls are built honeycombed to allow free circulation of air below the floor, the holes in the wall being $\frac{1}{2}$ B wide by 65 mm deep, as illustrated in Figure 4.15.

The practical guidance in Approved Document C requires a space of at least 75 mm from the top of the concrete to the underside of a wall plate and at least 150 mm to the underside of the floor joists, concrete oversite at least 100 mm
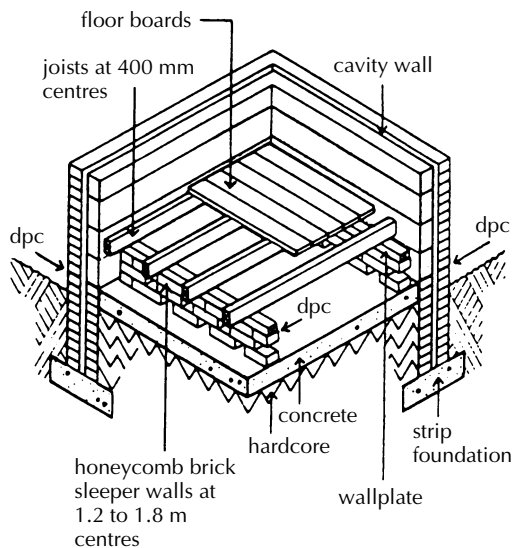
Figure 4.15   Sleeper walls, joists and boards.

thick on a hardcore bed or concrete at least 50 mm thick on a dpm of 1200 gauge polythene on a bed that will not damage it. Under floor ventilation should have a free path between opposite sides, with openings equivalent to 1500 mm^2 for each metre run of wall.

Suspended timber floors

Wall plate

A wall plate is a continuous length of softwood timber that rests along the length of a wall. The function of a wall plate for timber joists is two-fold. It forms a firm level surface on which the timber floor or roof joists can bear and to which the floor joists can be nailed. The wall plate spreads the point loads from joists uniformly along the length of the wall below. The plate makes it considerably easier to fix floor and ceiling joists to the wall. A wall plate is usually a 100 × 75 mm timber and is laid on its widest face so that there is a 100 mm surface width on which the timber joists bear. A dpc should be laid on top of the sleeper walls under the wall plate to prevent any moisture rising through sleeper walls to the timber floor.

Floor joists

Floor joists are rectangular sections of sawn softwood timber from 38 to 75 mm thick and from 75 to 225 m deep, spaced from 400 to 600 mm apart. The minimum bearing for floor and roof joists is 35 mm (Approved Document A). The span of a joist is the distance measured along its length between walls that support it. The sleeper walls built to support the joists are usually 1.8 m apart or less, thus the span of the joists is 1.8 m or less. The best method of supporting the ends of the joists at external walls and at internal brick partitions is to build a honeycombed sleeper wall some 50 mm away from loadbearing walls to carry the ends of the joists, as illustrated in Figure 4.15. The sleeper wall is built away from the main wall to allow air to circulate through the holes in the honeycomb of the sleeper wall. The ends of the joists are positioned so that they are 50 mm clear of the inside face of the wall.

From a calculation of the dead and imposed loads on the floor the most economical size and spacing of joists can be selected from the tables in Approved Document A and from this the spacing of the sleeper walls to support the joists can be found. Similarly the thickness of the floorboards to be used will determine the spacing of the joists, the thicker the board the greater the spacing of the joists. Timber floorboards, chipboard, MDF (medium density fibre board) or plywood boards are laid across the joists and they are nailed to them to form a firm, level floor surface.

Floor finish

Floor boards for timber floors are usually 16, 19, 21 or 28 mm thick and 65, 90, 113 or 137 mm wide and up to about 5 m in length. The common way of cutting
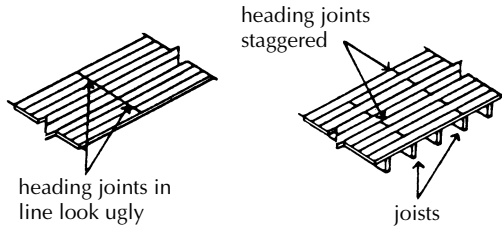
Figure 4.16   Heading joints.

boards is with a projecting tongue on one edge and a groove on the opposite edge of each board. The tongued and grooved boards (T & G) are laid across the floor joists and cramped together. The boards, as they are cramped up, are nailed to the joists with two nails to each board bearing on each joist. The joint between the end of one board and the end of another is described as the heading joint. The heading joints in floorboards should always be staggered in some regular manner. Obviously the heading joint ends of boards must be cut so that the ends of both boards rest on a joist to which the ends are nailed. A usual method of staggering heading joints is illustrated in Figure 4.16.

   The recommendation in Approved Document A is that T & G boards nailed to joists spaced at up to 500 mm should be at least 16 mm finished thickness and at wider spacing up to 600 mm, 19 mm finished thickness. Boards of compressed wood chips, chipboard, are commonly used today as a substitute for T & G boards. The use of large tongued and grooved chipboard minimises joints. The boards are nailed or screwed to the timber joists.

Ventilation
The space below this type of floor is usually ventilated by inserting air bricks, made of terracotta or plastic, in the walls below the floor so that air from outside the building can circulate at all times under the floor. This is to prevent stagnant air and the possibility of dry rot developing under the floor. The dimensions of airbrick are 215 × 65, 215 × 140 or 215 × 215 mm. These bricks are built into external and internal walls for each floor to provide 1500 mm of ventilation for each metre run of wall. The bricks are built in just above ground level and below the floor, as illustrated in Figure 4.17.

Thermal insulation
To meet the requirements of the Building Regulations for resistance to heat transfer through ground floors it may be necessary to insulate suspended timber ground floors that have a ventilated space below. The most practical way of insulating a suspended timber ground floor is to fix mineral wool roll, mat or quilt or semi-rigid slabs between the joists. Rolls or quilt of loosely felted glass fibre or mineral wool are supported by a mesh of plastic that is draped over
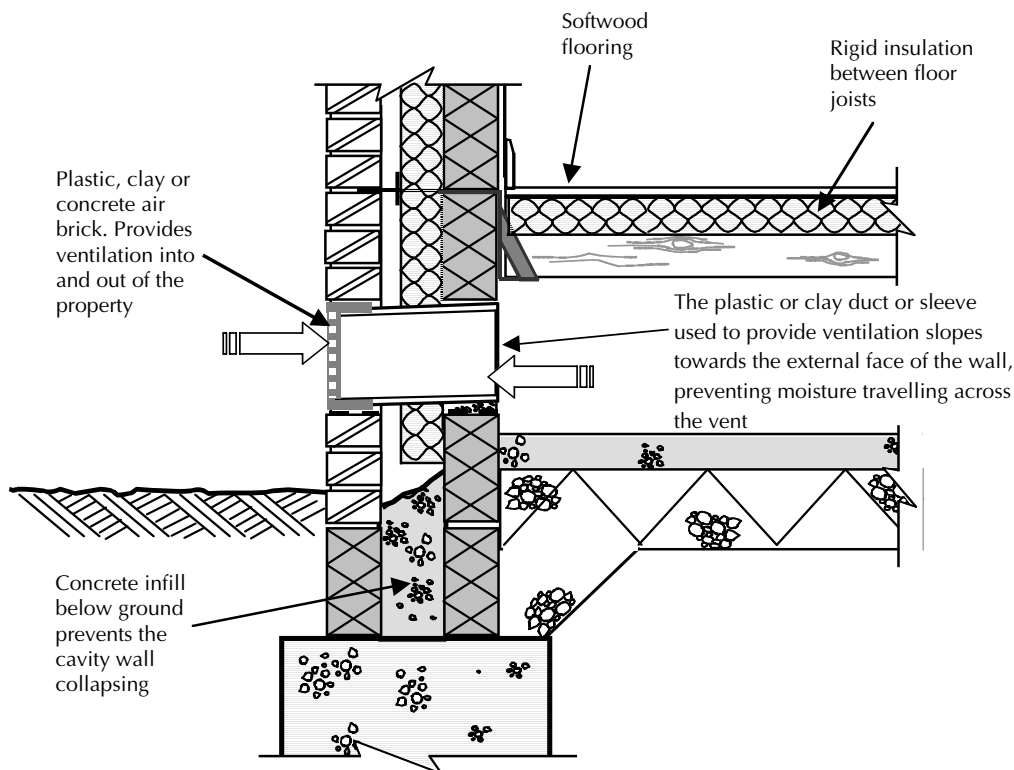
Figure 4.17   Section through wall and floor junction, with airbrick and under-floor ventilation.

the joists and stapled in position to support the insulation. Semi-rigid slabs or batts of fibreglass or mineral wool are supported between the joists by nails or battens of wood nailed to the sides of the joists.

4.5 Resistance to the passage of heat

Approved Document L includes provision for the insulation of ground floors. The current requirement of AD:L1 is that ground floors should have a minimum insulation value (U value) of 0.25 W/m °K. To reduce heat losses through thermal bridges around the edges of solid floors and so minimise problems of condensation and mould growth, edge insulation should be used, particularly where the wall insulation is not carried down below the ground floor slab. Edge insulation is formed either as a vertical strip between the edge of the slab and the wall or under the slab around the edges of the floor as illustrated in Figure 4.18. The depth (width) of the strips of insulation varies from 0.25 m to 1 m.
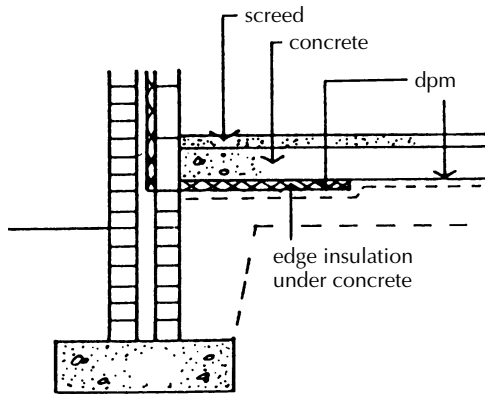
Edge insulation under concrete
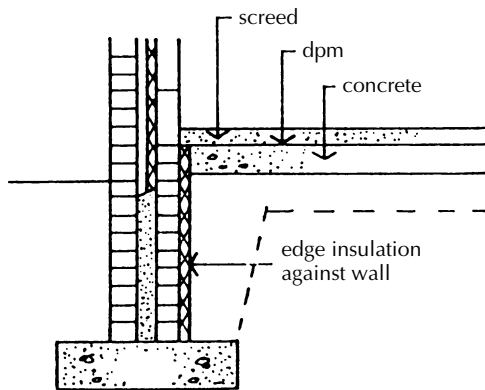
Edge insulation vertical

Figure 4.18   Perimeter insulation to ground slab.

Achieving insulation values

The only practical way of improving the insulation of a solid ground floor to the required U value is to add a layer of rigid insulation board with a high thermal resistance to the floor. The layer of insulation may be laid below a chipboard or plywood panel floor finish or below a timber boarded finish or below the screed finish to a floor or under the concrete floor slab. With insulation under the screed or slab it is important that the density of the insulation board is sufficient to support the load of the floor itself and imposed loads on the floor. A density of at least 16 kg/m³ is recommended for domestic buildings.

The advantage of laying the insulation below the floor slab is that the high density slab, which warms and cools slowly (slow thermal response)
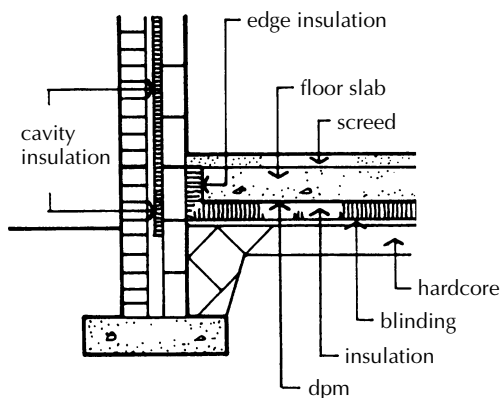
Figure 4.19 dpm over insulation under floor slab.

in response to changes in temperature of the constant low output heating systems, will not lose heat to the ground. With the insulation layer and the dpm below the concrete floor slab it is necessary to continue the dpm and insulation up vertically around the edges of the slab to unite with the dpc in walls as illustrated in Figure 4.19.

Although it is possible to insulate the whole floor area with an insulating material that has the required U value of the floor (e.g. using insulation with a U value of 0.25 W/m °K) it may be better to take into account other materials and the perimeter area method as described in approved Document L1.

Approved Document L1 states that a ground floor should not have a U-Value exceeding 0.25 W/m °K if the 'Elemental Method' of compliance is to be used. This can often be achieved without the need for insulation if the perimeter area ratio is less than 0.12 m/m^2 for solid ground floors or less than 0.09 m/m^2 for suspended floors. However, in most situations some ground floor insulation will be necessary. The Building Regulations section L1 Appendix C provides simple methods for determining U values, which will suffice for most common construction and ground conditions. More rigorous procedures are given in BS EN ISO 13370 (1998) and in CIBSE Guide, Section A3 (1999).

Ground floor U values from approved tables
Assuming a building has an overall perimeter of 30 m and a ground floor area of 45 m^2 (Figure 4.20). The floor construction consists of 150 mm reinforced concrete slab and **98 mm** of rigid insulation (thermal conductivity **0.04 W/m K**). Only the insulation is included in the calculation of thermal resistance. The thermal resistance of the insulation is obtained by dividing the thickness (in metres) by the conductivity 0.098/0.04 = **2.45 m^2 K/W**.

The perimeter to area ratio is equal to 0.67m/m^2. Table C1 Approved Document L1 provides values for 0.65 and 0.70. In this case 0.65 should be used as 0.67 is closer to 0.65 than 0.70.

Overall perimeter =

9 + 6 + 6 + 3 + 3 + 3 = 30 m

Area =

(3 × 3) + (6 × 6) = 45 m²

$$\frac{\text{perimeter length}}{\text{area}} = \text{P/A}$$

30/45 = 0.67 = P/A
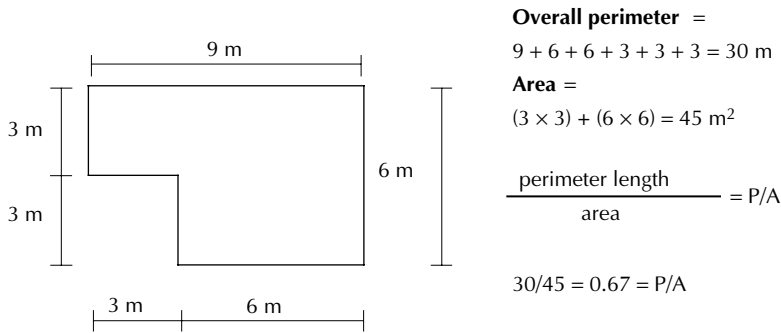
Figure 4.20   Perimeter length/area (m/m²) ratio.

The U value that corresponds to the thermal resistance of 2.45 m² K/W is obtained by interpolation between the U values that correspond with 2 and 2.5 m² K/W. (See Table 4.1.) For example:

$$U = 0.30 \times \frac{2.5 - 2.45}{2.5 - 2.0} + 0.26 \times \frac{2.45 - 2}{2.50 - 2}$$

$$= (0.30 \times 0.1) + (0.26 \times 0.9)$$

$$= 0.03 + 0.234$$

$$= 0.264 \text{ W/m}^2 \text{ K} + \text{ U value of the floor}$$

It should be noted that when using Table C1 interpolation is carried out between the columns. However, for all other tables the interpolation should be carried out between the rows. Tables are also provided for calculating the effect of edge insulation.

Calculating thickness of insulation using the floor perimeter/area method

Tables are provided in Approved Document L1 for determining the thickness of insulant (insulation) for the following types of floor construction (see Table 4.1 and Figure 4.21) using the perimeter/area method.

In order to use the tables the perimeter of the floor needs to be calculated (m) and divided by the floor area (m²). Using this perimeter/area (P/A) ratio the thickness of insulation can be found for different insulating materials with different thermal conductivities (see Table 4.2 and Figure 4.22).

Where the wall insulation is in the cavity or on the inside face of the wall it is necessary to avoid a cold bridge across the foundation wall and the edges of the slab by fitting insulation around the edges of the slab or by continuing the insulation down inside the cavity, as illustrated in Figure 4.23.

An advantage of positioning the dpm above the insulation is that it can be used to secure the upstand edge insulation in place while concrete is being

Table 4.1   U values for solid ground floors – Perimeter area method
Partial Extract for Table C1 U-values (W/m²K) for solid ground floors

	Thermal resistance of all over insulation (m² K/W)					
	0	**0.5**	**1**	**1.5**	**2**	**2.5**
Perimeter/ area (m/m²)						
0.50	.70	.50	.40	.33	.28	.24
0.55	.74	.52	.41	.34	.28	.25
0.60	.78	.55	.43	.35	.29	.25
0.65	.82	.57	.44	.35	.30	.26
0.70	.86	.59	.45	.36	.30	.26

The thermal resistance of the insulation is = 2.45 m² K/W

(2.45?)

section of table 4.1 Thermal resistance of all-over insulation (m²K/W)		
	2	2.5
Perimeter/area		
0.65	0.30	.26

placed. If the dpm is laid below the insulation it is necessary to spread a separating layer over the insulation to prevent wet screed running into the joints between the insulation boards. The separating layer should be building paper or 500-gauge polythene sheet. To avoid damage to the insulation layer and the dpm it is necessary to take care in tipping, spreading and compacting wet concrete or screed. Scaffold boards should be used for barrowing and tipping concrete.

A   Solid floors in contact with the ground
(Table A13 doc L1)

B   Suspended timber ground floors
(Table A14 doc L1)

C   Suspended concrete beam and block ground floors
(Table A15 doc L1)
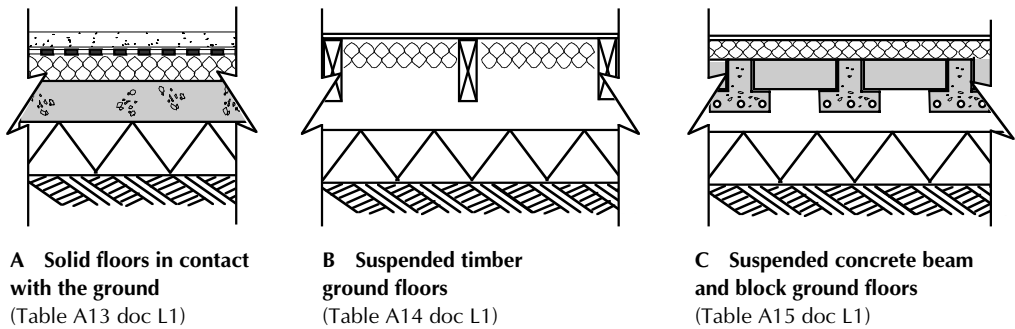
Note: when insulation is placed between floor joists, the thermal conductivity occurs through the joists as well as the insulation, thus the U value should be increased (See Table A4 Corrections to U-values Approved Document L1)

Figure 4.21   A, B & C Insulation within different types of floor construction.

Table 4.2 Extract from Table A13 Approved document L1

| | SOLID FLOORS IN CONTACT WITH GROUND Insulation thickness (mm) for U value of 0.25 W/m² K Thermal conductivity of insulant (W/m.K) | | | | | | |
P/A	0.020	0.025	0.030	0.035	0.040	0.045	0.050
1.00	61	76	91	107	122	137	152
0.90	60	75	90	105	120	135	150
0.80	58	73	88	102	117	132	146
0.70	57	71	85	99	113	128	142
0.60	54	68	82	95	109	122	136
0.50	51	64	77	90	103	115	128
0.40	47	59	70	82	94	105	117
0.30	40	49	59	69	79	89	99
0.20	26	32	39	45	52	58	65

Materials for under floor insulation

Any material used as an insulation layer to a solid, ground supported floor must be sufficiently strong and rigid to support the weight of the floor or the weight of the screed and floor loads without undue compression and deformation. To meet this requirement one of the rigid board or slab insulants is used.

To achieve a U value of 0.25 W/m²K with an insulation material with a thermal conductivity of 0.045 w/m.K.

First calculate the ratio between the perimeter and area:
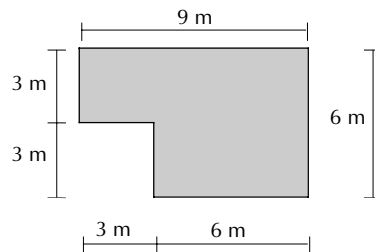
Overall perimeter =
9 + 6 + 6 + 3 + 3 + 3 = 30 m
Area =
(3 x 3) + (6 × 6) = 45 m²

$$\frac{\text{perimeter length}}{\text{area}} = P/A$$

30/45 = .67 = P/A

Then use the thermal conductivity of the material and the Perimeter / Area ratio to determine the thickness of insulation required from Table A13 in part L1 of the building regulations

The thermal conductivity of the insulation is 0.045 W/m.K
P/A = 0.67 (round up to 0.7)
From Table 4.2 the minimum thickness of insulation required is 128 mm

Figure 4.22 Perimeter length/area (m/m²) ratio (example 2).
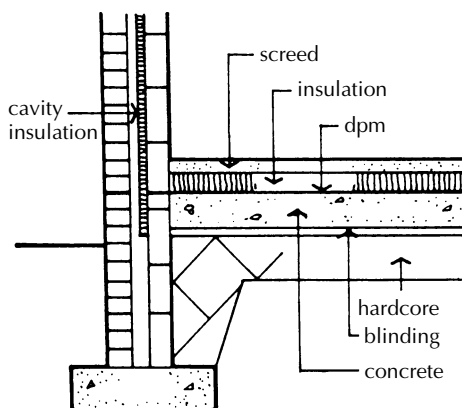
Figure 4.23   DPM under insulation and screed.

The thickness of the insulation is determined by the nature of the material from which it is made and the construction of the floor, to provide the required U value.

Some insulants absorb moisture more readily than others and may be affected by ground contaminants. Where the insulation layer is below the concrete floor slab, with the dpm above the insulation, an insulant with low moisture absorption characteristics should be used. The materials commonly used for floor insulation are mineral wool slabs, extruded polystyrene, cellular glass and rigid polyurethane foam boards.

4.6 Reinforced concrete upper floors

Reinforced concrete floors have a better resistance to damage by fire and can safely support greater superimposed loads than timber floors of similar depth. The resistance to fire, required by building regulations for most offices, large blocks of flats, factories and public buildings, is greater than can be obtained with a timber upper floor, therefore some form of reinforced concrete floor has to be used. The types of reinforced concrete floor that are used for small buildings are self-centering 'T' beams and infill blocks, hollow beams and monolithic insitu cast floors. The word centering is used to describe the temporary platform on which insitu cast concrete floors are constructed and supported until the concrete has sufficient strength to be self-supporting. The term self-centering is used to define those precast concrete floor systems that require no temporary support.

Precast 'T' beam and infill block floor

This type of reinforced concrete floor is much used for comparatively small spans and loads, described earlier. The advantage of this system is that two

workers can safely handle the units without the need for lifting gear. For floors that need a greater bearing capacity, the block and beam floors can be finished with a concrete topping. The structural topping ties the blocks and beams together making a composite floor. The 'T' beams are placed at 270 mm centres with their ends built into walls or bearing on beams of at least 90 mm. The blocks are placed in position and the floor completed with a layer of structural concrete topping, 50 mm thick spread and levelled ready for a screed or power floated finish as illustrated in Figure 4.24. The purpose of the constructional concrete topping is to spread the loads on the floor over the blocks and beams. The underside, or soffit, of the floor is covered with plaster or will provide support for a suspended ceiling. This comparatively cheap floor system provides reasonable resistance to airborne sound and resistance to fire. This floor system is particularly suited for use as a raised (suspended) ground floor.
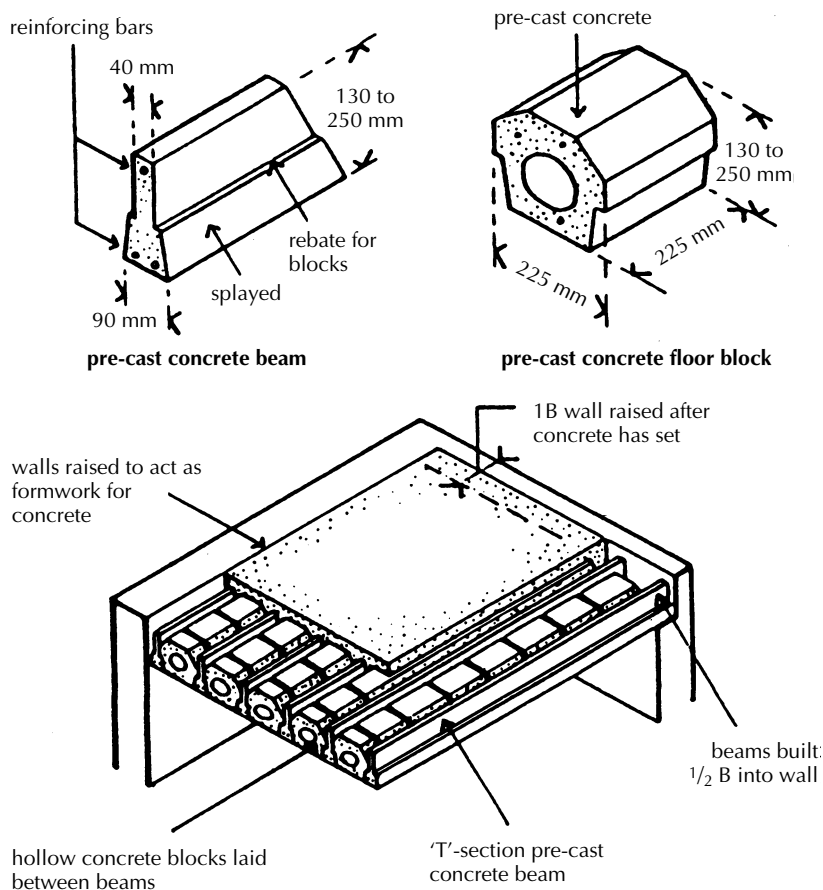
Figure 4.24   Pre-cast concrete beam and block floor.
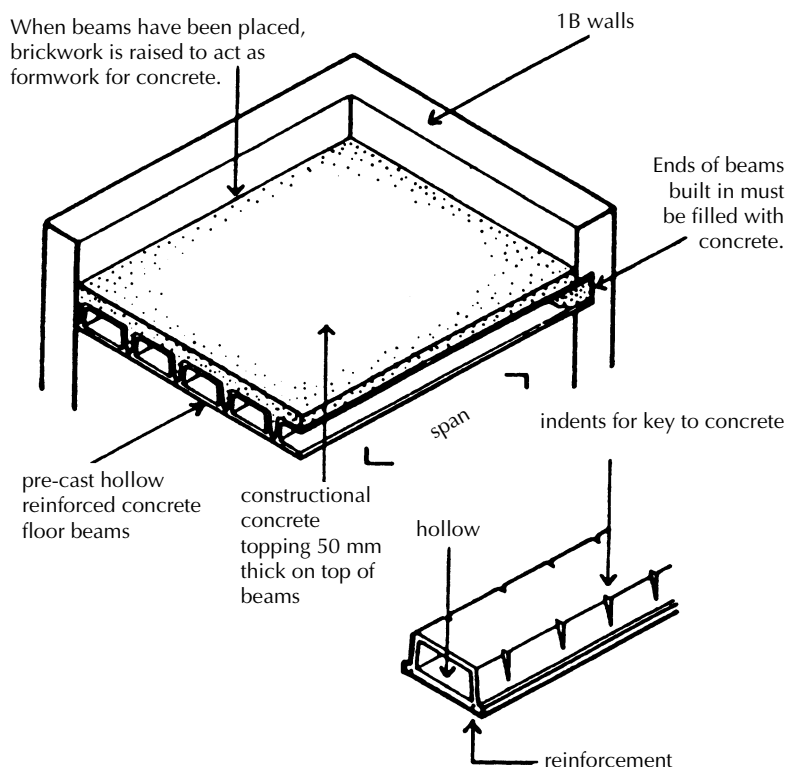
Figure 4.25   Hollow concrete beam floor.

Hollow beam floor units

Hollow, reinforced concrete beams are precast around inflatable formers to produce the hollow cross-section. The beams are rectangular in section with the steel reinforcement cast in the lower angles of the beam. The sides of the beams are indented to provide a key for the concrete topping, as illustrated in Figure 4.25.

The beams are usually 355 mm wide, from 130 to 205 mm deep and up to 6m long. The depth of the beam depends on the superimposed loads and the span. Because of their length and weight, lifting gear is necessary to raise and lower the beams into place. The beams are placed side by side with their ends bearing $\frac{1}{2}$ B on or into brick loadbearing walls or on to steel beams. If the ends of the beams are built into walls the ends should be solidly filled with concrete because a hollow beam is not strong enough to bear the weight of heavy brickwork. The walls of the beams are made thin so that they are light in weight for transporting and hoisting into position. The thin walls of the beams are not strong enough to carry the direct weight of furniture. So that

A   Concrete floor beams

B   Each beam is hoisted into position and placed on the
supporting walls or beams

Photograph 4.3   Hollow concrete floor beams.

point loads are transferred and distributed, a layer of concrete usually 50 mm
thick is levelled over the beams. The concrete is termed 'constructional concrete
topping'; it is an integral part of this floor system, spread and levelled on top
of the beams. Photograph 4.3 refers.

Reinforced concrete and clay block floor

The resistance to damage by fire of a reinforced concrete floor depends on the
protection, or cover, of concrete underneath the steel reinforcement. Under the

action of heat, concrete is liable to expand and come away from its reinforcement. If, instead of concrete, pieces of burned clay tile are cast into the floor beneath the reinforcing bars the floor has a better resistance to fire than it would have with a similar thickness of concrete.

The particular advantage of this type of floor is its good resistance to damage by fire, and it is sometimes termed 'fire-resisting reinforced concrete floor'. To keep the dead weight of the floor as low as possible, compatible with strength, it is constructed of insitu reinforced concrete beams with hollow terracotta infilling blocks cast in between the beams. A typical TC (terracotta) block is shown in Figure 4.26. This type of floor has to be given temporary support with timber or steel temporary support (centering). The TC blocks and the reinforcement are set out on the temporary support, and pieces (slips) of clay tile are placed underneath the reinforcing bars. Concrete is then placed and compacted between the TC blocks and spread 50 mm thick over the top of the blocks.

The floor is built into walls $\frac{1}{2}$ B thick as shown. This type of floor can span up to 5 m and the depth of the blocks, the depth of the finished floor and
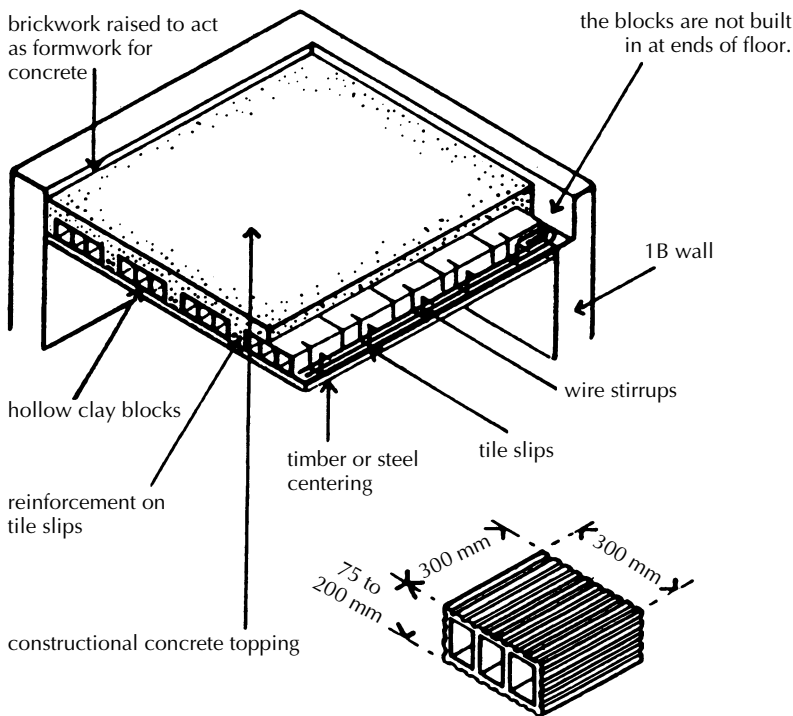
Figure 4.26   Terracotta block floor.

the size and number of reinforcing bars depend on the superimposed loads and span. This type of floor is rarely used in developed countries because it is labour intensive. Considerable labour is involved in placing the hollow TC pots, reinforcement and temporary support. The flooring system is suited to those countries where hollow clay blocks are extensively used for infill walls to reinforced concrete frame buildings.

Monolithic reinforced concrete floor

A monolithic reinforced concrete floor is one unbroken solid mass, between 100 and 300 mm thick, of insitu reinforced concrete. To support the concrete while it is still wet and plastic, and for 7 days after it has been placed, temporary support (formwork or centering) has to be used. This takes the form of rough timber marine plywood boarding or steel sheets, supported on timber or steel beams and posts. The steel reinforcement is laid out on top of the support and raised 20 mm or more above the formwork by means of small concrete blocks, wire chairs or plastic spacers (called spacers), which are tied to the reinforcing bars with wire. The wet concrete is then placed and spread over the reinforcement and the formwork. It is compacted and levelled off. Figure 4.27 illustrates a single monolithic concrete floor with part of the concrete taken away to show reinforcement and timber centering.

Steel reinforcing bars are cast into the underside of the floor with 20 mm or more concrete cover below them to prevent the steel rusting and to give it
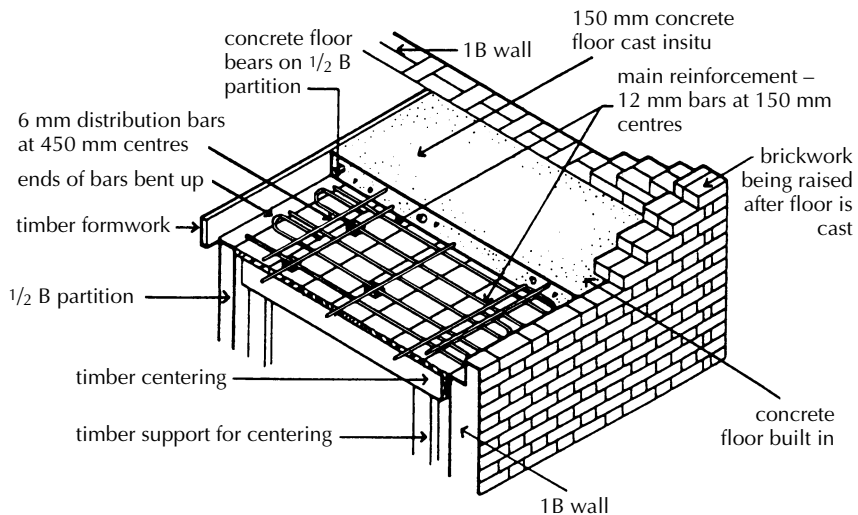
Figure 4.27   Monolithic reinforced concrete floor.

protection in case of fire. The thicker the concrete cover to reinforcement the greater the resistance of the floor to fire. Structural floors are reinforced with a combination of high tensile steel and mild steel reinforcement. The high tensile steel is usually positioned at the bottom of the concrete floor to withstand any tensile forces.

Floors are usually designed to span in one direction, although they can span in two directions, especially if supported by walls on all sides. From the loads and the span the required thickness of concrete can be determined and then the cross-sectional area of steel reinforcement determined. The main reinforcement usually consists of 12 mm diameter high tensile steel rods spaced from 150 to 225 mm apart, and these span across the floor between walls supporting the floor. The diameter will increase as the loads imposed and the span of the floor increases. Mild steel rods, 6 mm in diameter, are wired across the main reinforcement spaced 450 to 900 mm apart, and are called distribution rods or bars. These rods are tied to the main reinforcement with wire and keep the main reinforcing rods correctly spaced whilst the concrete is being placed. The main purpose of these mild steel rods is to assist in distributing point loads on the floor, ensuring that the forces are uniformly distributed over the mass of the concrete.

Because the formwork required to give temporary support to a monolithic concrete floor tends to obstruct and hence delay building operations, 'self-centering' concrete floors (concrete floors with permanent formwork) are often used for multi-storey. Such monolithic concrete floors are used for heavily loaded and specially designed construction and for stairs, ramps and small spans.

Steel 'rib-deck' concrete floors

Profiled cold rolled steel decking is often used as permanent formwork. Profiled steel is placed between supporting walls or beams, reinforcement is positioned and concrete is poured into place. Once the concrete has set the profiled steel formwork becomes mechanically bonded to the concrete forming a matrix floor. The steel formwork also acts as reinforcement to concrete floor. This type of floor construction has become one of the principal floor systems for multi-storey framed buildings, as described in *Barry's Advanced Construction of Buildings.*

Functional requirements specific to concrete floors

Fire safety
The resistance to fire of a reinforced concrete floor depends on the thickness of concrete cover to steel reinforcement, as the expansion of the steel under heat will tend to cause the floor to crack and ultimately give way. Also, if steel is

exposed to the direct heat of the fire it will rapidly lose its strength. Approved Document B specifies the minimum concrete cover required between the external face of the concrete and the reinforcement. The concrete cover offers protection to the steel reinforcement in the event of a fire.

Resistance to the passage of heat

A reinforced concrete upper floor that is exposed to outside air and one that separates a heated from an unheated space has to be insulated against excessive transfer of heat by a layer of insulating material. The insulation is usually laid on the top of the floor under a screed or boarded platform floor surface.

Resistance to the passage of sound

The mass of a concrete floor will provide some appreciable resistance to the transfer of airborne sound. Sound energy is absorbed in the mass of dense concrete. Where it is necessary to provide resistance to impact sound a form of floating floor surface may be necessary. Floating floors separate the surface floor from the structure, which reduces the ability of the sound vibrations to travel from the floor finish to the structural materials.

4.7 Timber upper floors

Floor joists

Strength and stability

A timber floor is supported by softwood timber joists, usually between 38 and 75 mm thick and 75 to 235 mm deep. The required depth of joists depends on the dead and imposed loads and the span. The spacing of the joists is usually 400, 450 or 600 mm measured from the centre of one joist to the next. Tables in Approved Document A set out the required size of timber joists for given spans and two strength classes, with given spacing of joists for various loads for single-family dwellings of up to three storeys. To economise in the use of timber, the floor joists of upper floors usually span the least width of rooms, from external walls to internal loadbearing partition walls. The maximum economical span for timber joists is between 3.6 and 4.0 m.

Double floors – spanning timber floor joists between steel beams

Where the span of a timber floor is greater than the lengths of timber commercially available, or where such lengths become uneconomical, it is convenient to use a steel or timber beam to provide intermediate support for timber joists. This combination of beam and the joists is described as a double floor. Steel beams are generally used because of their small section.
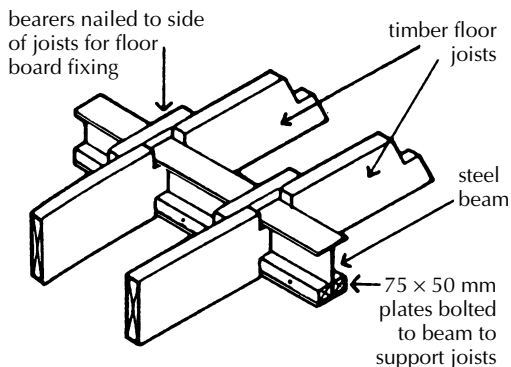
Figure 4.28 Double floor.

The supporting steel beam may be fixed under the joists or wholly or partly hidden in the depth of the floor. To provide a fixing for the ends of the joists, timber plates are bolted to the bottom flange of the beam and the ends of the joists are scribed (shaped) to fit into the joist over the plates to which they are nailed. To provide a fixing for floorboards timber bearers are nailed to the sides of joists across the supporting steel beam, as illustrated in Figure 4.28. The ends of the supporting steel beam are built into loadbearing walls and bedded on a pad stone to spread the load along the wall. Where the supporting steel beam projects below the ceiling it is cased in plasterboard, which will also act as fire protection.

Strutting between joists
To maintain joists in the vertical position in which they were initially fixed, timber strutting is used. Herringbone strutting consists of short lengths of softwood timber about 50 × 38 mm nailed between the joists, as illustrated in Figure 4.29. As the struts are nailed between the joists they tend to spread and secure the joists in an upright position. To provide rigid strutting between walls, wedges are fixed between the joists and walls at both ends of the strutting.

The recommendation in Approved Document A is that joists which span less than 2.5 m do not require strutting, those that span from 2.5 to 4.5 m require one row of struts at mid-span and those with more than 4.5 m span require two rows of struts spaced one-third of the span.

As an alternative to herringbone strutting, solid strutting may be used. This consists of short lengths of timber, of the same section as the joist, that are nailed between the joists either in line or staggered, as in Figure 4.29. This is not usually as effective a system of strutting as the herringbone system, because unless the short solid lengths are cut very accurately to fit the sides of the joists they do not firmly strut between the joists.
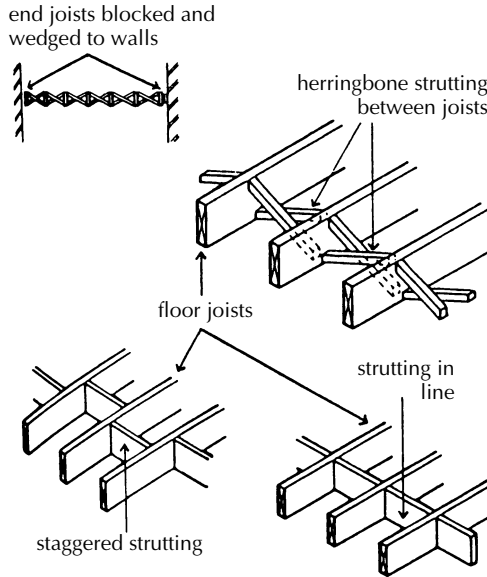
Figure 4.29   Strutting between joists.

End support for floor joists

For stability, the end of floor joists must have adequate support from walls or beams. Timber joists built into the inner skin of a cavity wall must not project into the cavity or across separating or compartment walls where they may encourage the spread of fire. It may be wise to treat the ends of the joists with a preservative against the possibility of decay due to moisture penetration. It is common in such situations for the joists to bear directly on the brick or block wall with plastic spacers under each joist to level the joists (Figure 4.30). As
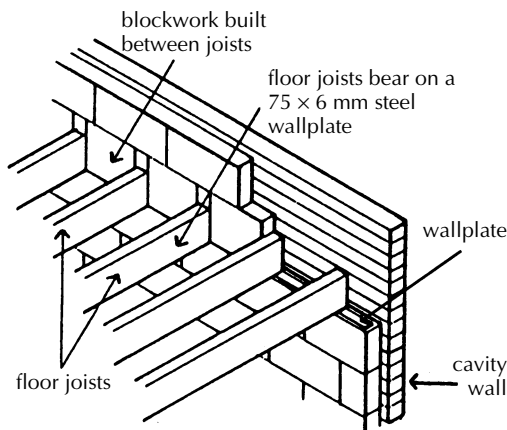
Figure 4.30   Joists ends built into cavity wall.

A   Galvanised steel joist hanger

B   Hangers spaced and positioned along the party wall ready to receive joists

C   Where extra strength is required within the floor (for example around stair openings) joist may be doubled up
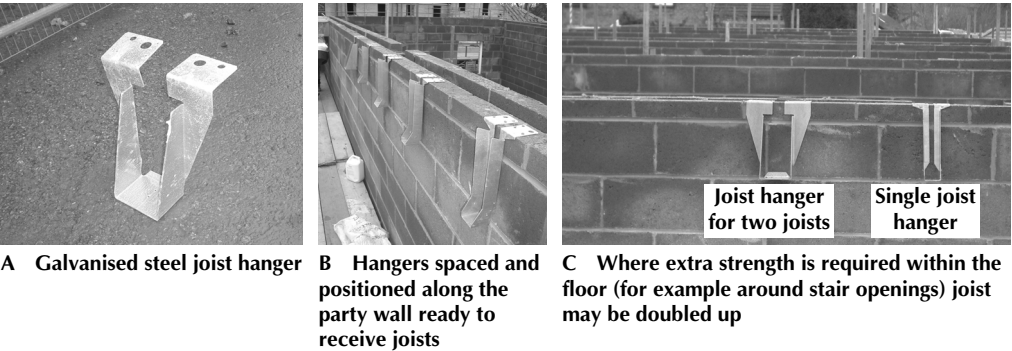
Photograph 4.4   Joist hangers.

an alternative to building in the ends of timber joists, joist hangers are used. Galvanised, pressed steel joist hangers are made with straps for building into horizontal courses and a stirrup to support a joist end (Figure 4.31). The joist hangers are built into horizontal brick or blockwork as walls are raised and the joists fitted and levelled later or the joists, with the hangers nailed to their ends, are given temporary support as the brick or blockwork is raised and the hangers are built into horizontal courses. The advantage of joist hangers is that joist ends are not exposed to possible damp, and there is no need for cutting brick or block to fit around joists.

Lateral restraint for walls

To provide lateral support to walls by floors, Approved Document A recommends the use of straps or joist hangers to provide lateral support for walls at
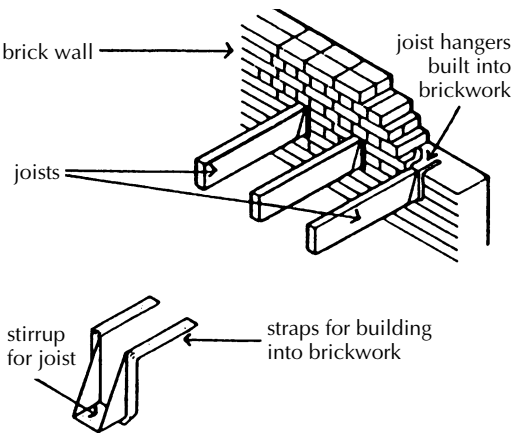
Figure 4.31   Galvanised pressed steel joist hanger.

D Joists fixed into steel joist hanger. Horizontal strutting holds the joists firmly in place

E Joist and joist hangers positioned around floor opening

Photograph 4.4   (*continued*).

each storey floor level above ground to transfer lateral forces on walls, such as wind, to floors.

Lateral support is required to any external, compartment or separating wall longer than 3 m at every floor, roof and wall junction and any internal load-bearing wall, not being a compartment or separating wall, of any length at the top of each storey and roof.

Walls should be strapped to floors at intervals of not more than 2 m with 30 × 5 mm straps (see Chapter 5). Straps are not required in the longitudinal direction of joists in houses of not more than two storeys, if the joists are at no more than 1.2 m centres and where the joists are supported by restraint type joist hangers, illustrated in Figure 4.32, at not more than 2 m centres.

Notches and holes
Notches and holes are often cut into timber joists so that electric cables, water and gas pipes can pass through. So that the notches and holes do not seriously weaken the strength of the floor, limitations of size are given as practical guidance by the Building Regulations. Notches should be no deeper than 0.125 times the depth of a joist and cut no closer to the support than 0.07 of the span, nor further away than 0.25 times the span. Holes should be of no greater diameter than 0.25 the depth of joist, drilled on a neutral axis and not less than two diameters apart (centre to centre) and located between 0.25 and 0.4 times the span from the support, as illustrated in Figure 4.33.

Floor finish
The surface of a timber upper floor is the same as that described for a timber ground floor.
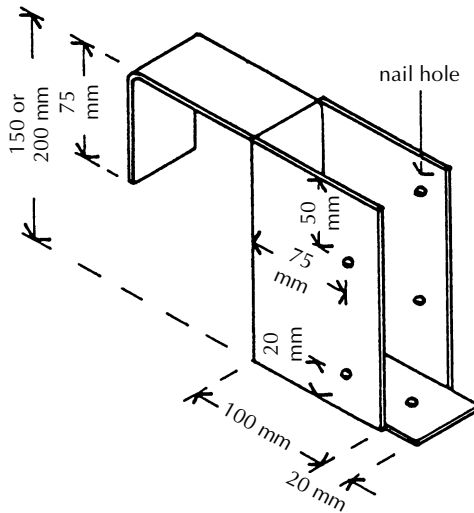
Figure 4.32   Galvanised steel restraint joist hanger.

Functional requirements specific to timber upper floors

Fire safety

Structural floors of dwelling houses of two or three storeys are required to have a minimum period of fire resistance of half an hour. Floors that meet the half hour fire resistance include:

❏ Floor with tongued and grooved boards or sheets of plywood or chipboard at least 15 mm thick, joists at least 37 mm wide and a ceiling of 12.5 mm plasterboard with 5 mm neat gypsum plaster finish
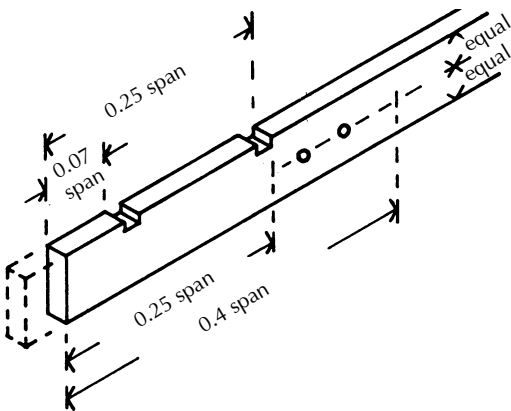
Figure 4.33   Notches and holes in timber joists.

❑ Floor with 21 mm thick tongued and grooved boards, sheets of plywood or chipboard on joists at least 37 mm wide with a ceiling of 12.5 mm plasterboard with joints taped and filled

Resistance to the passage of heat

Timber upper floors that are exposed to outside air, such as floors over carports, have to be insulated against heat transfer to meet the requirements of the Building Regulations. The maximum U value of exposed floors has to be 0.25 W/m^2 K, the same as external floors. Insulation can be placed between the joists in the form of low density glass fibre or mineral wool rolls, mats or quilts can be laid on to the ceiling finish or semi-rigid batts, slabs or boards of insulating material can be friction fitted between joists and supported by nails or wood battens nailed to the sides of joists. To avoid cold bridges the insulation must extend right across the floor in both directions up to surrounding walls.

Resistance to the passage of sound

A boarded timber floor with a rigid plasterboard ceiling affords poor resistance to the transmission of sound. To reduce the transmission of airborne sound it is necessary to increase the mass of a floor to restrict the flow of energy through it. To reduce the transmission of impact sound it is necessary to provide some soft material, such as a carpet, between the cause of the impact and the hard surface.

The traditional method of insulating timber floors against sound was to spread a layer of plaster or sand, termed 'pugging', on rough boarding fixed between the joists or on expanded metal lath and plaster, as illustrated in Figure 4.34. Pugging is effective in reducing the transmission of airborne sound but has little effect in deadening impact sound. To deaden impact sound it is necessary to lay some resilient material on the floor surface or between the floor surface material and the structural floor timbers. The combination of a resilient layer under the floor surface and pugging between joists will effect appreciable reduction of impact and airborne sound. Where the floorboards
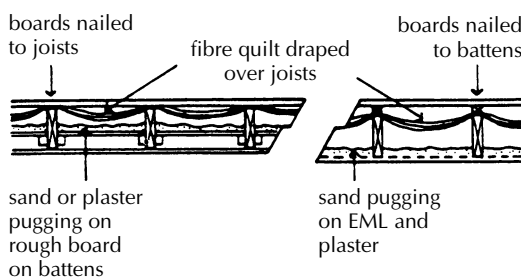
Figure 4.34   Sound insulation of timber floor.

are nailed directly to joists, through the resilient layer, as illustrated in Figure 4.34, much of the impact sound deadening effect is lost. Approved Document E includes specifications for the construction of concrete and timber floors.

For concrete floors the resistance to airborne sound depends mainly on the mass of the concrete. Resistance to impact sound may be provided by a soft covering of carpet or other resilient material. Alternatively, the resistance to airborne sound can be provided mainly by the mass of the concrete floor and partly by a floating top layer. The top layer consists of a platform of T & G boards or chipboard nailed to timber battens that are laid on a 13 mm thickness of resilient material as indicated in Figure 4.35, with the edges of the resilient layer turned up around the edges of the floating top layer. This floating layer is laid loose on the concrete base. The carpet or other finish can be laid on top.

For timber floors pugging is placed or fixed between the joists for resistance to airborne sound and a floating floor is used to resist impact sound and to some extent resist airborne sound. This platform floor is constructed as a floor of 18 mm thick T & G boards or chipboard with all joints glued. The boarded platform is spot bonded to a base of 19 mm thick plasterboard. The boarded platform is laid on a 25 mm thick layer of resilient mineral fibre on a floor base of 12 mm thick boarding or chipboard nailed to the joints, as illustrated

concrete floor

timber floor
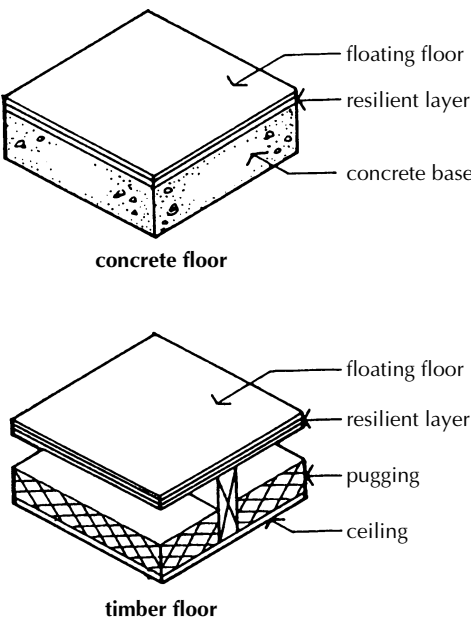
Figure 4.35   Sound insulation of floors.

platform floor of T & G boards
bonded to plasterboard laid on
resilient layer of mineral
fibre mat on floor base
of chipboard nailed
to joists

fibre
strip

absorbent blanket of
mineral fibre over
plasterboard ceiling
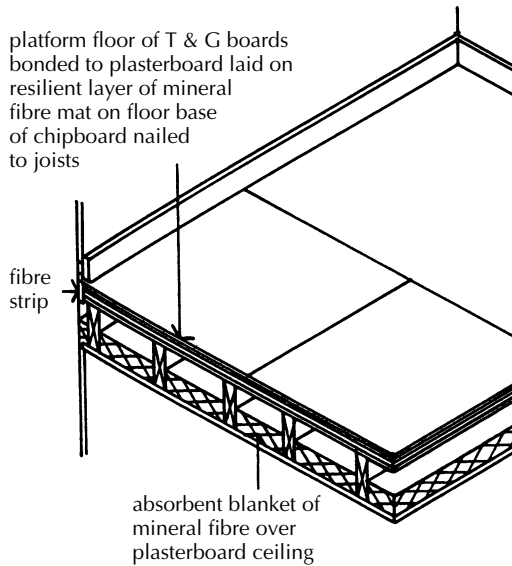
Figure 4.36   Platform floor.

in Figure 4.36. The ceiling comprises two layers of plasterboard, with joints staggered, to a finished thickness of 30 mm on which 100 mm of absorbent mineral fibre is laid. To provide a level floor surface for platform floors it is necessary to fix the floorboards by nailing them to battens or by fixing the boards to a firm level base of plasterboard or similar material, so that the boards can be cramped together. The boards are bonded to the plasterboard base with strips or pads of adhesive to keep them flat, as the tongues in the edges of the boards are cramped up into the grooves of adjacent boards to produce a level floor finish.

To minimise flanking transmission of sound from the floor surface to the surrounding walls, a strip of resilient fibre material is fixed between the edges of platform, floors and surrounding solid walls, and a gap of at least 3 mm is left between the skirting and floating floors. To limit the transmission of airborne sound through gaps in the construction it is important to seal all gaps at junctions of wall and ceiling finishes and to avoid or seal breaks in the floor around service pipes. Mineral wool and other resilient materials that are specifically manufactured for their acoustic properties can be used under the floorboards and as absorbent pugging between the floor joists

Party floors

The function of a party floor is the same as that of a party wall. In residential units it may be necessary to make more substantial separations between floors resisting the passage of fire and sound. Plasterboard and mineral wool can be

Typical methods of improving acoustic and fire performance in compartment and separate floors
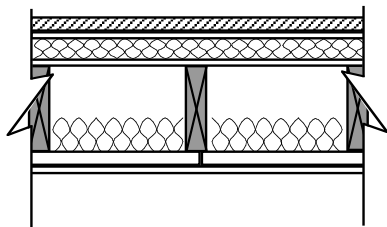
A   Mineral wool and composite plaster board
21 mm softwood floor boarding
15 mm Gyproc sound block (composite board)
Rigid acoustic insulation on top of existing floor (mineral wool).
100 mm acoustic wool between joists
15 mm Gyproc sound block below existing ceiling
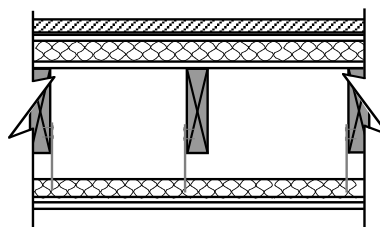
B   Ceiling suspended from floor
21 mm softwood floor boarding
15 mm Gyproc sound block (composite board)
Rigid acoustic insulation on top of existing floor (mineral wool).
80 mm acoustic wool on hung ceiling provides continuous sound and fire resistance
Two layers of 15 mm Gyproc sound block suspended from floor joists
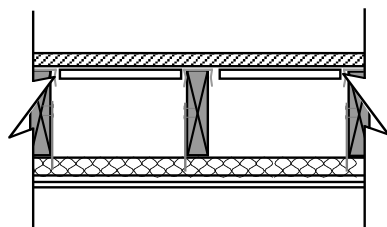
C   Ceiling hung suspended from floor with resilient channels placed on joists and sound resisting planks between joist
21 mm softwood floor boarding
19 mm sound block planks between joists (plaster based composite board)
100 mm acoustic wool on hung ceiling provides continuous sound and fire resistance
Two layers of 15 mm Gyproc sound block suspended from floor joists
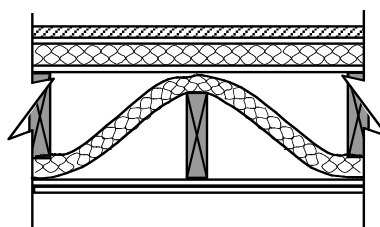
D   Separate ceiling joists or sub-floor isolates floor from ceiling
21 mm softwood floor boarding
15 mm Gyproc sound block (composite board)
Rigid acoustic insulation on top of existing floor (mineral wool).
100 mm acoustic wool between joists lapped over and under joists
Two layers of 15 mm Gyproc sound block below existing ceiling

All tapered joints are taped and filled. Screw fixing is recommended where the composite plaster boards are fixed direct to timber joists, rather than nail fixing, as this minimises the risks of fixing defects.

Figure 4.37   A, B, C and D Timber compartment floors (adapted from www.british-gypsum.bpb.com).

used to improve the acoustic performance and fire resistance. In the Building Regulations a distinction is made between floors that act as sound barriers, referred to as separating floors, and floors that resist the passage of fire, referred to as compartment floors. Floors may be required to resist the passage of fire and sound and thus are both separating floors and compartment floors (Figure 4.37). Further information on separating and compartment walls can be found in the *British Gypsum White Book* (2003) www.british-gypsum.bpb.com.

5 Walls

A wall is a continuous, usually vertical structure, which is thin relative to its length and height. External walls help to provide shelter from our environment and internal walls divide buildings into rooms or compartments. The prime function of an external wall is to provide shelter against wind, rain and the daily and seasonal variations of outside temperature normal to its location, for reasonable indoor comfort. To provide adequate shelter a wall should have sufficient strength and stability to be self-supporting and also to support roofs and upper floors. To differentiate the structural requirements of those walls that carry the loads from roofs and upper floors in addition to their own weight from those that are freestanding and carry only their own weight, the terms loadbearing and non-loadbearing are used. The majority of walls for single, double and triple storey buildings are constructed with loadbearing masonry walls or are framed from timber, steel or concrete. The type of wall used will generally depend on the availability of materials and labour, economic factors and the design approach.

5.1 Functional requirements

The function of a wall is to enclose and protect a building or to divide space within a building. To provide a check that a particular wall construction satisfies a range of functional requirements it is convenient to adopt a list of specific requirements. The commonly accepted requirements of a wall are:

- ❏ Strength and stability
- ❏ Resistance to weather and ground moisture
- ❏ Durability and freedom from maintenance
- ❏ Fire safety
- ❏ Resistance to the passage of heat
- ❏ Resistance to airborne and impact sound
- ❏ Security
- ❏ Aesthetics

Strength and stability
The strength of the materials used in wall construction is determined by the strength of a material in resisting compressive and tensile stress and the way in which the materials are put together. The usual method of determining the compressive and tensile strengths of a material is to subject samples of

the material to tests to assess the ultimate compressive and tensile stresses at which the material fails in compression and in tension. From these tests the safe working strengths of materials in compression and in tension are set. The safe working strength of a material is considerably less than the ultimate strength, to provide a safety factor against variations in the strength of materials and their behaviour under stress. The characteristic working strengths of materials, to an extent, determine their use in the construction of buildings.

The moderate compressive and tensile strength of timber members has long been used to construct a frame of walls, floors and roofs for houses. The compressive strength of well burned brick combined with the durability, fire resistance and appearance of the material commends it as a walling material. The sense of solidity and permanence and the compressive strength of stone made it the traditional walling material for many larger buildings. Steel and concrete are used principally for their considerable strength as the structural frame members of large buildings. In the majority of small buildings, such as houses, the compressive strength of brick and stone is rarely fully utilised because the functional requirements of stability and exclusion of weather dictate a thickness of wall in excess of that required for strength alone.

Stability of a wall may be affected by foundation movement, eccentric loading, lateral forces (wind) and expansion due to changes in temperature and moisture. Eccentric loads (those not acting on the centre of the wall), such as from floors and roofs, and lateral forces, such as wind, tend to deform and overturn walls. The greater the eccentricity of the loads and the greater the lateral forces, the greater the tendency of a wall to deform, bow out of the vertical and lose stability. To prevent loss of stability, due to deformation under loads, building regulations and structural design calculations set limits to the height or thickness ratios (slenderness ratios) to provide reasonable stiffness against loss of stability due to deformation under load. To provide stiffness against deformation under load, lateral (horizontal) restraint is provided by walls and roofs that are tied to the wall, and by intersecting walls and piers that are bonded or tied to the wall as stiffening against deformation along the length of walls. Irregular profile walls have greater stiffness against deformation than straight walls because of the buttressing effect of the angle of the zigzag, chevron, offset or serpentine profile of the walls, illustrated in Figure 5.1. The more pronounced the chevron, zigzag, offset or serpentine of the wall, the stiffer it will be. Similarly the diaphragm and fin walls, described in *Barry's Advanced Construction of Buildings*, are stiffened against overturning and loss of stability by the cross ribs or diaphragms built across the wide cavity to diaphragm walls and the fins or piers that are built and bonded to straight walls in the fin wall construction.

Resistance to weather and ground moisture
A requirement of the Building Regulations is that walls should adequately resist the passage of moisture to the inside of the building. Moisture includes
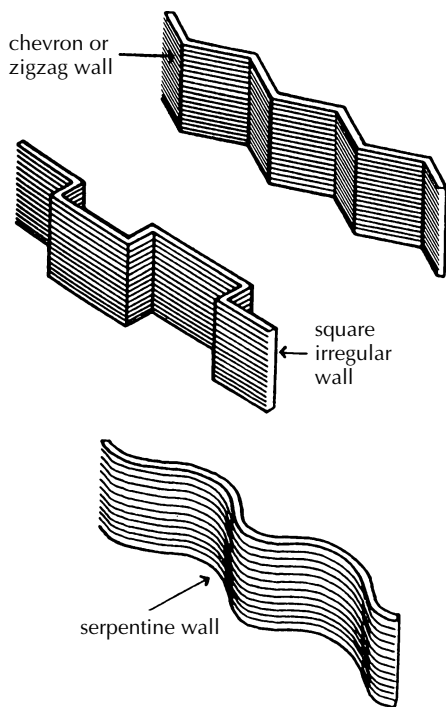
Figure 5.1   Irregular profile walls.

water vapour and liquid water. Moisture may penetrate a wall by absorption of water from the ground that is in contact with the foundations or through rain and snow falling on the wall. Impermeable materials are used to form dpcs and dpms to prevent water rising in floors and walls. The ability of a wall to resist the passage of water to its inside face depends on its exposure to wind driven rain and the construction of the wall.

The exposure of a wall is determined by its location and the extent to which it is protected by surrounding higher ground, or sheltered by surrounding buildings or trees, from rain driven by the prevailing winds. In Great Britain the prevailing westerly winds from the Atlantic Ocean cause more severe exposure to driving rain along the west coast of the country than do the cooler and drier easterly winds on the east coast. British Standard 5628: Part 3 defines five categories of exposure as: very severe, moderate/severe, sheltered/moderate, sheltered, and very sheltered. A map of Great Britain, published by the Building Research Establishment, shows contours of the variations of exposure across the country. The contour lines, indicating the areas of the categories of exposure, are determined from an analysis of the most severe likely spells of wind driven rain, occurring on average every three years, plotted on a 10 km grid. The

analysis is based on the 'worst case' for each geographical area, where a wall faces open country and the prevailing wind, such as a gable end wall on the edge of a suburban site facing the prevailing wind or a wall of a tall building on an urban site rising above the surrounding buildings and facing the prevailing wind.

Where a wall is sheltered from the prevailing winds the exposure can be reduced by one category in sheltered areas of the country and two in very severe exposure areas of the country. Local knowledge and specific site characteristics (e.g. detailing and weathering of neighbouring buildings) are also valuable indicators of exposure. The cavity wall has been particularly successful in separating the internal and external environments, transferring loads and resisting rain and wind penetration (Figure 5.2).

Durability and freedom from maintenance

The durability of a wall is indicated by the frequency and extent of the work necessary to maintain minimum functional requirements and an acceptable appearance. Where there are agreed minimum functional requirements such as exclusion of rain and thermal properties, the durability of different walls may be compared through the cost of maintenance over a number of years.

Fire safety

Walls (combined with doors and windows) are an important element in providing fire protection. The two principal considerations are the structural integrity of the wall in a fire and the surface spread of flame, which is determined by the materials used.

Specifying a minimum period of fire resistance for the elements of the structure may restrict premature failure of the structural stability of a building in a fire. An element of structure is defined as part of a structural frame, a load-bearing wall and a floor. The requirements are that the elements should resist collapse for a minimum period of time in which the occupants may escape in the event of fire. Periods of fire resistance vary from 30 minutes for dwelling houses with a top floor not more than 5 m above ground, to 120 minutes for an industrial building, without sprinklers, whose top floor is not more than 30 m above ground.

Fire may spread over the surface of materials that encourage the spread of flame across their surfaces. In Approved Document B is a classification of the performance of linings relative to surface spread of flame over wall and ceiling linings and limitations in the use of thermoplastic materials used in roof lights and lighting diffusers.

Thermal insulation and thermal bridging

The building interior is heated by the transfer of heat from heaters and radiators to air (conduction), the circulation of heated air (convection) and the radiation

of energy from heaters and radiators to surrounding colder surfaces (radiation). This internal heat is transferred through colder enclosing walls, roofs and floors by conduction, convection and radiation to colder outside air.

Conduction

The rate at which heat is conducted through a material depends mainly on the density of the material. Dense metals conduct heat more rapidly than less dense gases. Metals have high conductivity and gases low conductivity. Conductivity is the amount of heat per unit area, conducted in unit time through a material of unit thickness, per degree of temperature difference. Conductivity is expressed in watts per metre of thickness of material per degree kelvin (W/m K) and usually denoted by the Greek letter λ (lambda).

Convection

The density of air that is heated falls, the heated air rises and is replaced by cooler air. This in turn is heated and rises so that there is a continuing movement of air as heated air loses heat to surrounding cooler air and the cooler surfaces of ceilings, walls and floors. It is not possible to quantify heat transfer by convection, so the usual practice is to make an assumption of likely total air changes per hour or volume (litres) per second and then calculate the heat required to raise the temperature of the incoming cooler air introduced by ventilation.

Radiation

Radiant energy from a body, radiating equally in all directions, is partly reflected and partly absorbed by another body and converted to heat. The rate of emission and absorption of radiant energy depends on the temperature and the nature of the surface of the radiating and receiving bodies. The heat transfer by low temperature radiation from heaters and radiators is small, whereas the very considerable radiant energy from the sun that may penetrate glass and that from high levels of artificial illumination is converted to appreciable heat inside buildings. An estimate of solar heat gain and heat gain from artificial illumination may be assumed as part of the heat input to buildings.

Transmission of heat

Because of the complexity of the combined modes of heat transfer through the fabric of buildings it is convenient to use a coefficient of heat transmission as a comparative measure of transfer through the external fabric of buildings. This air-to-air heat transmittance coefficient, the U value, takes account of the transfer of heat by conduction through the solid materials and gases, convection of air in cavities and across inside and outside surfaces, and radiation to and from surfaces. The U value is the rate of heat transfer in watts through one square metre of a material or structure, when the combined radiant and air temperatures on each side of the material or structure differ by one kelvin

(1 °C). A high rate of heat transfer is indicated by a high U value, a low rate of heat transfer by a low U value. Methods of compliance are given in Approved Document Part L1 and Part L2.

Ventilation

The sensation of comfort is highly subjective and depends on the age, activity and to a large extent on the expectations of the subject. For comfort, good health and wellbeing in buildings it is necessary to provide a controlled means of ventilation through windows and/or ventilators. For general guidance a number of air changes per hour is recommended, depending on the activity common to rooms or spaces. One air change each hour for dwellings and more frequent air changes for kitchen and sanitary accommodation is recommended to minimise condensation of moisture-laden, warm air on cold internal surfaces in those rooms.

Thermal insulation

The figures given for the thermal conductivity of materials (lambda value) are based on measurements in controlled environments (laboratories), not on their actual performance in the field (a real building in a particular environment). Standard lambda values assume good quality control and defect free

Driving rain is prevented from entering the building.

Loads from the roof are transferred to the internal leaf of the cavity.

The floor loads are transferred to the internal wall leaf through joists which are built into the wall or via joist hangers, as shown here.

The cavity prevents water transferring from the external face of the wall to the internal wall and acts as a thermal insulant.

Wall ties link the two skins of the cavity, improving the stability of each skin. The ties can also be used to hold insulation sheets in place.

Insulation increases the thermal resistance of the wall.

Materials such as bricks, blocks and mineral wool will absorb sound energy and help resist the transfer of sound.

Figure 5.2   Cavity wall: Resisting the external environment and transferring loads.

External environment

Internal environment

Lintel

Heat is conducted through the concrete lintel and the brickwork.

Where a continuous mass of solid material occurs, heat is conducted through the material.

Conduction will also occur through the solid parts of a window unless thermal breaks are introduced. The head, cill and window frame often act is thermal bridges if not designed correctly.

Cill

If gaps occur in the insulation or mortar drops on the cavity tie forming a continuous bridge of material, a cold bridge will occur.

Section of window head and cill

Figure 5.3   Thermal bridging: section of window head and cill.

construction on site. Unfortunately, quality control on site has been shown to be less than satisfactory and with the best will in the world it is harder to assemble details on site than in a laboratory. Thus U values are a reasonable guide to the thermal performance of the building fabric, nothing more, nothing less. Add in some thermal bridging (see below) and the actual thermal performance of the fabric may be less than that calculated. With this in mind we would urge readers to try to move away from an attitude of trying to meet the minimum requirements as stated in the Approved Documents and try to better the thermal performance requirements. Methods of calculating U values are illustrated in the Approved Documents.

Thermal bridging
With increased levels of thermal insulation being introduced into the building fabric the problem of thermal bridging has become a major design

**Potential thermal bridging through window
and wall jamb**

Where there is no insulation and the blockwork returns to
meet the brickwork, at the reveal, heat energy will be
conducted out of the building.

Typical thermal bridges

- Single glazing

- Metal window
  frames

Thermal
bridge

- Solid masonry
  reveals

Where the internal
environment is humid
(warm moisture-laiden air),
condensation may form on
cold spots.

Where insulation is missing or
mortar has dropped onto the
cavity tie, a cold bridge will
form.
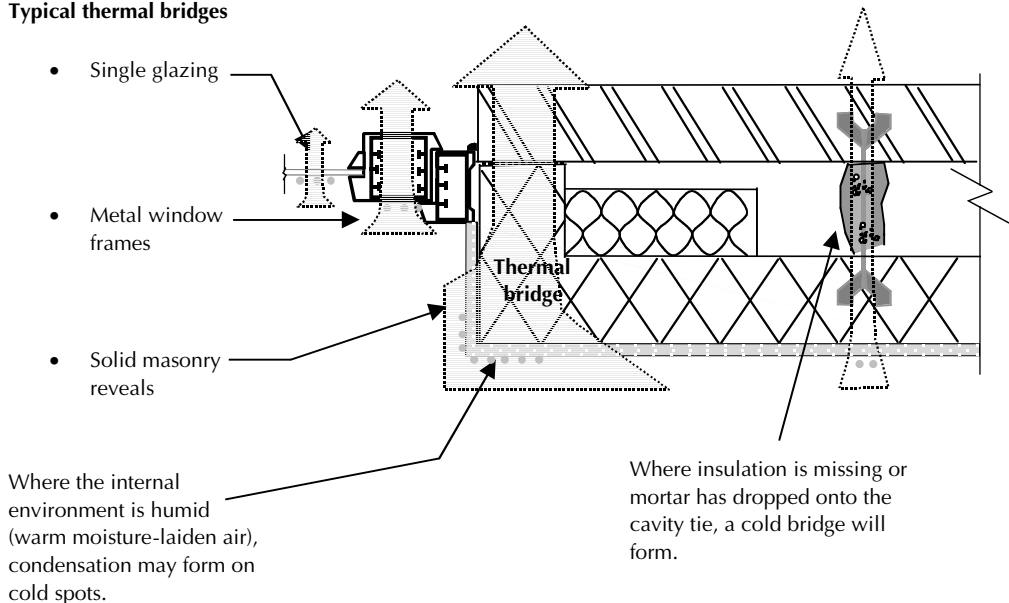
Plan: section of window jamb

Figure 5.4   Thermal bridging: plan of cavity wall return and window.

consideration. Thermal bridging (known as a 'cold bridge' in cold climates)
is caused by appreciably greater thermal conductivity through one part of a
wall than the rest of the wall, which can cause condensation and encourage
mould growth. Openings in walls are areas where thermal bridging can occur
if not detailed correctly (Figures 5.3 and 5.4). The greater the level of thermal
insulation, the greater the effect of any thermal bridges, a point to be borne
in mind when improving the thermal insulation of existing buildings that are
likely to have existing thermal bridges. Thermal bridging can be designed out,
or their effect minimised, through careful detailing and careful assembly on site
to ensure continuity of insulation. Care must be taken, however, to consider
constructability because if the detail is difficult to insulate on site, it is highly
probable that it will not be constructed as detailed, thus defeating the object of
the exercise.

Solid walls and some uninsulated cavity walls are
susceptible to interstitial and surface condensation

External   **Internal**   **External**   **Internal**
(Cold)   **(Warm)**   **(Cold)**   **(Warm)**

Warm
moist air

Cold   Condensation forms
surface   on and within cold
                materials

Warm
moist air
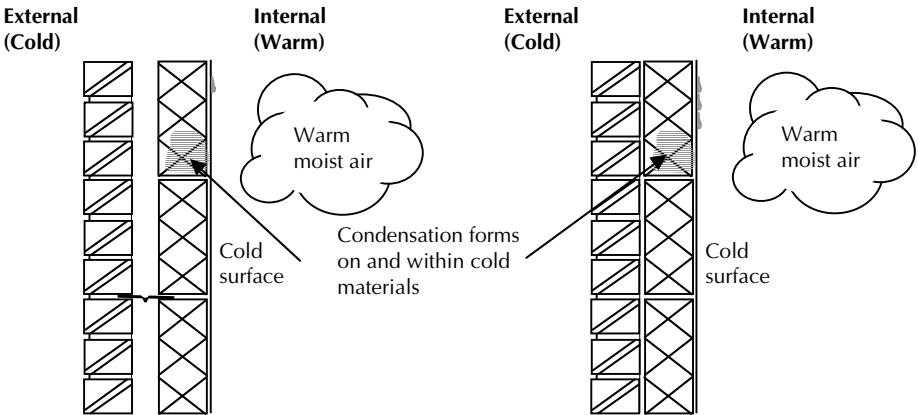
Cold
surface

The warm internal air can hold a considerable
amount of moisture, which is generated by
people, gas burners and kettles. If the air becomes
colder it has to give up the water it contains. As the
warm air hits cold objects water will be deposited
on them.

As the warm, moist air comes into contact
with the cold face of the wall, condensation
forms on the surface of the wall. If the wall
is permeable, condensation will also form
inside the cold wall (interstitial
condensation).

External   **Internal**
(Cold)   **(Warm)**

Warm
moist air

As well as keeping
the internal
environment warm,
the insulation also
keeps the internal leaf
of the wall warm.

Warm
surface

As the block work and
plaster are on the warm
side of the insulation they
remain warm, thus
condensation does not form
on the surface or within the
wall.
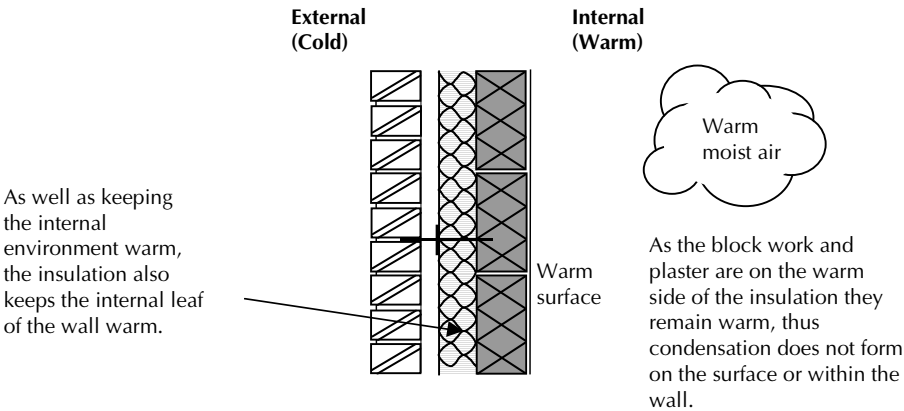
Figure 5.5   Condensation and walls.

Resistance to the passage of heat

For reasonable indoor comfort, the external walls should provide resistance to
excessive transfer of heat, both from inside to outside and from outside to inside
during periods of cold or hot, seasonal, outside temperatures. To maintain

Dense closely packed material

Lightweight material with pockets of air between particles

Heat stored, transferred and released

HEAT SOURCE

Resists storage and transfer of heat

Dense materials allow easier transfer of heat energy, but also store more heat energy

Lightweight materials that are cellular resist the transfer of heat and store less heat energy

Figure 5.6   Heat transfer and storage in lightweight and dense materials.

reasonable and economical conditions of thermal comfort in buildings, walls should provide adequate insulation against excessive loss or gain of heat, have adequate thermal storage capacity, and the internal face of walls should be at a reasonable temperature. Condensation is likely to form on cold internal surfaces (Figure 5.5).

For insulation against loss of heat, lightweight materials with low conductivity are more effective than dense materials with high conductivity, whereas dense materials have better thermal storage capacity than lightweight materials (Figure 5.6). The materials that are most effective in resisting heat transfer are those of a fibrous or cellular nature in which very many small pockets of air are trapped to act as insulation against the transfer of heat. Because of their lightweight nature these materials do not have sufficient strength to serve as part of the structure of a wall by themselves. Lightweight insulating materials are either sandwiched between materials that have strength or behind those that resist penetration of wind and rain, or serve as internal wall finishes.

Where a building is heated it is advantageous to use the thermal storage capacity of a dense material on the inside face of the wall with the insulating properties of a lightweight material behind it (Figure 5.7). Here the combination of a brick or dense block inner leaf, a cavity filled with some lightweight insulating material and an outer leaf of brick against penetration of rain is of advantage. The internal blockwork can act as a heat store. As the building is heated the dense blocks will become warm; once the heating is turned off the dense blocks will release the warmth back into the building. This helps to level out temperature changes when heating cycles are intermittent.

**External
(Cold)**   **Internal
(Warm)**

When the wall is
well insulated
only a small
amount of heat
energy escapes
through the wall.

Heat
energy
stored

Heat energy
returns back
into building

With the dense blockwork on
the inside of the insulation, the
blockwork is heated up and
retains (stores) the heat. If the
temperature within the building
drops the blockwork releases
the heat energy back into the
building.

Figure 5.7   Thermal storage in walls.

Resistance to the passage of sound

Sound is transmitted as airborne sound and impact sound. Airborne sound
is generated as cyclical disturbances of air from, for example, a radio, which
radiate from the source of the sound with diminishing intensity with distance
from the source (Figure 5.8). The vibrations in the air caused by the sound
source will set up vibrations in enclosing walls and floors which will cause
vibrations of air on the opposite side of walls and floors.

Impact sound is caused by contact with a surface, for example, the slamming
of a door or footsteps on a floor which set up vibrations in walls and floors that
in turn cause vibrations of air around them that are heard as sound (Figure 5.8).
The most effective insulation against airborne sound is a dense barrier such as
a solid wall, which absorbs the energy of the airborne sound waves. The heav-
ier and more dense the material of the wall the more effective it is in reducing
sound. The Building Regulations require walls and floors to provide reason-
able resistance to airborne sound between dwellings and between machine
rooms, tank rooms, refuse chutes and habitable rooms (see Party walls and
floors).

The more dense the material the more readily it will transmit impact sound.
A knock on a part of a rigid concrete frame may be heard some considerable
distance away. Insulation against impact sound will therefore consist of some
absorbent material that will act to cushion the impact, such as a carpet on a
floor, or serve to interrupt the path of the sound, as for example the absorbent
pads under a floating floor. Noise generated in a room may be reflected from
the walls and ceilings and build up to an uncomfortable intensity inside the

Breaks in the structure, such as the cavity, prevent structure-borne sound progressing. The sound energy must change back to air-borne sound to pass through the cavity.

The dense interconnected materials allow the sound energy to travel through the structure.

Impact sound

Dense blockwork absorbs the sound energy

Air-borne sound

Intensity of sound diminishes the further it travels
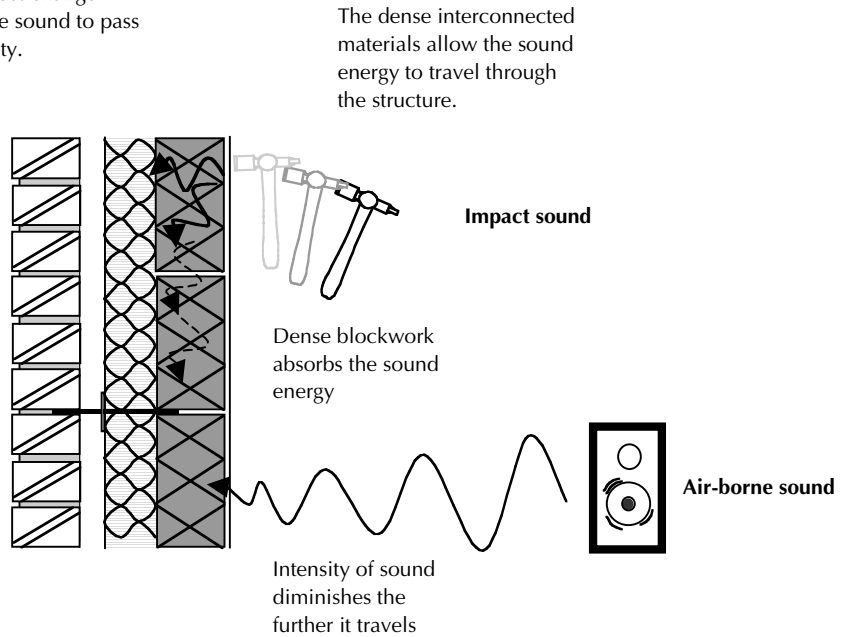
Figure 5.8   Air-borne sound and impact sound.

room, particularly where the wall and ceiling surfaces are hard and smooth. To prevent the build up of reflected sound some absorbent material should be applied to walls and ceilings, such as acoustic tiles or curtains, to absorb the energy of the sound waves.

Security

Walls, in conjunction with doors and windows, provide a barrier to unwanted visitors. In domestic properties unauthorised entry to property usually takes place through doors or windows. In commercial premises, especially where buildings contain goods that are subject to theft, it is not unusual for forced entry to occur through walls and roofs. Therefore the resistance of the wall to, for example, ram raiding, may be a primary function of the wall.

Aesthetics

Walls are important visually. They are a vital component in the design of a building, making a major contribution to the character of the building. Standards of acceptable appearance may vary widely from person to person,

particularly with unfamiliar wall surface materials such as glass and plastic coated sheeting, so that it is difficult to establish even broadly based comparative standards of acceptable appearance. Choice of materials will be dependent upon satisfying the functional and performance requirements listed above and on satisfying the designer's aesthetic goals: other considerations being the walling materials used on neighbouring buildings and any requirements of the local planning authority. The appearance of the walls may also influence whether loadbearing or framed construction is chosen.

Materials

Some of the most popular materials that are used for walls are:

- ❏ Stone, both natural and artificial (reconstituted) stone
- ❏ Bricks and blocks, primarily of clay or concrete
- ❏ Timber, used as a cladding and also in a structural capacity
- ❏ Concrete, used in a decorative and structural capacity
- ❏ Steel, used primarily in a structural capacity
- ❏ Glass, used as a rainscreen and also in a structural capacity

Other materials are used, some of which are becoming popular once again due to environmental concerns, and have been revisited using a combination of old and new technologies, examples being earth construction and straw bale construction. A less common method of constructing walls is the use of polystyrene hollow blocks filled with concrete.

5.2 Damp-proof courses (dpcs)

Function and position

The function of a damp-proof course (dpc) is to act as a barrier to the passage of moisture or water between the parts separated by the dpc. The movement of moisture or water may be upwards in the foundation of walls and ground floors, downwards in parapets and chimneys or horizontal where a cavity wall is closed at the jambs of openings.

There should be a continuous horizontal dpc above ground in walls whose foundations are in contact with the ground, to prevent moisture from the ground rising through the foundation to the wall above ground, which otherwise would make wall surfaces damp and damage wall finishes. The dpc should be continuous for the whole length and thickness of the wall and be at least 150 mm above finished ground level to avoid the possibility of a build up of material against the wall acting as a bridge for moisture from the ground as illustrated in Figure 5.9.
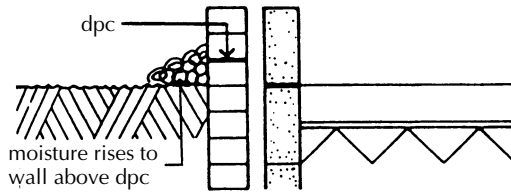
Figure 5.9   Damp-proof course above ground being bridged.

Flexible dpcs

Lead

A lead dpc should weigh not less than $19.5\,\text{kg/m}^2$ (Code No 4, 1.8 mm thick). Lead is an effective barrier to moisture and water. It is liable to corrosion in contact with freshly laid lime or cement mortar and should be protected by a coating of bitumen or bitumen paint applied to the mortar surface and both surfaces of the lead. Lead is durable and flexible and can suffer distortion due to moderate settlement in walls without damage; however, it is an expensive material and is little used today other than for ashlar stonework or as a shaped dpc in chimneys. Lead should be laid in rolls the full thickness of the wall or leaf of cavity walls and be lapped at joints along the length of the wall and at intersections at least 100 mm or the width of the dpc.

Copper

Copper is an effective barrier to moisture and water, it is flexible, has high tensile strength and can suffer distortion due to moderate settlement in a wall without damage; it is an expensive material and is rarely used today. Copper as a dpc should be annealed, at least 0.25 mm thick and have a nominal weight of $2.28\,\text{kg/m}^2$.

Bitumen damp-proof course

Bitumen dpcs are reasonably flexible and can withstand distortion due to moderate settlement in walls without damage. Bitumen dpcs, which are made in rolls to suit the thickness of walls, are bedded on a level bed of mortar and lapped at least 100 mm or the width of the dpc at running joints and intersections. Bitumen is economical, flexible, reasonably durable and convenient to lay. Bitumen is used in conjunction with other materials such as hessian, fibre, rubber or polymers to make a durable and workable dpc. The combination of a mortar bed, bitumen dpc and the mortar bed over the dpc for brickwork makes a comparatively deep mortar joint.

Polythene sheet

Polythene sheet for use as a dpc should be low-density polythene sheet of single thickness not less than 0.46 mm, weighing approximately $0.48\,\text{kg/m}^2$. Polythene sheet is flexible, can withstand distortion due to moderate settlement

in a wall without damage and is an effective barrier against moisture. It is laid on an even bed of mortar and lapped at least the width of the dpc at running joints and intersections. Being a thin sheet material, polythene makes a thinner mortar joint than bitumen dpc, and is sometimes preferred for that reason. Its disadvantage as a dpc is that it is fairly readily damaged by sharp particles in mortar or the coarse edges of brick.

Polymer-based sheets
Polymer-based sheets are thinner than bitumen sheets and are used where the thicker bitumen dpc mortar joint would be unsightly. This dpc material, which has its laps sealed with adhesive, may be punctured by sharp particles and edges.

Semi-rigid dpcs

Mastic asphalt
Mastic asphalt, spread hot in one coat to a thickness of 13 mm, is a semi-rigid dpc, impervious to moisture and water. Moderate settlement in a wall may well cause a crack in the asphalt through which moisture or water may penetrate. It is an expensive form of dpc, which shows on the face of walls as a thick joint, and it is rarely used.

Rigid dpcs

Slate
Thin slates are sufficiently impermeable to water to serve as an effective dpc in solid walls of brick or stone. Slates are laid on a bed of mortar in two courses, breaking joint as illustrated in Figure 5.10. Because of the small units of slate

$1\frac{1}{2}$ B wall in double Flemish bond

two courses of slates laid in cement mortar as dpc
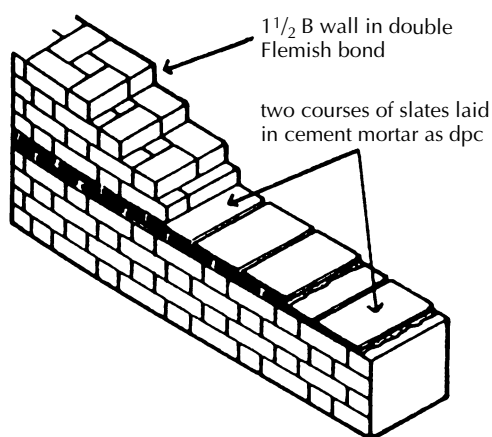
Figure 5.10   Slate damp-proof course.

and the joints being staggered this dpc can remain reasonably effective where moderate settlement occurs. To be effective the edges of the slates should be exposed on a wall face and not be covered, which makes a deep joint: a form of construction rarely used today.

Brick damp-proof courses

Two or three courses of dense engineering bricks may form an effective dpc. The effectiveness of the dpc is determined more by the permeability of the joining material than the bricks. This is rarely used these days other than as an architectural feature at the base of the building (and often in conjunction with a modern dpc).

Damp proof courses in cavity walls

A requirement of the Building Regulations is that the cavity should be carried down at least 150 mm below the level of the lowest dpc. A dpc in an external wall should ideally be at the same level as the dpm for the convenience of overlapping the two materials to make a damp-proof joint. Where the dpcs in both leaves of a cavity wall are at least 150 mm above outside ground level and the floor level is at, or just above, ground level, it is necessary to dress the dpm up the wall and into the level of the dpc. This is a laborious operation, which makes it difficult to make a moisture tight joint at angles and intersections. The solution is to lay the dpc in the inner leaf of the cavity wall, level with the dpm in the floor, as illustrated in Figure 5.11.

Where the level of the foundation is near the surface, as with trench fill systems, it may be convenient to build two courses of solid brickwork up to ground level on which the cavity wall is raised, as illustrated in Figure 5.12. As little vegetable topsoil has been removed, the floor level finishes some way above ground and the dpm in the floor can be united with the dpc at the same level. The cavity insulation is taken down to the base of the cavity to continue wall insulation down to serve in part as edge insulation to the floor construction.
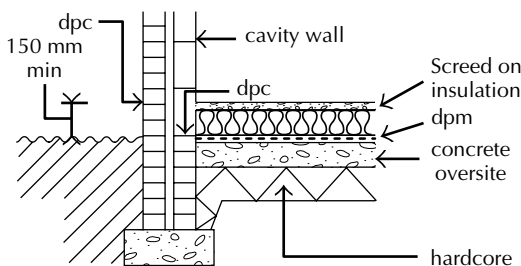
Figure 5.11   Damp-proof course at different levels.
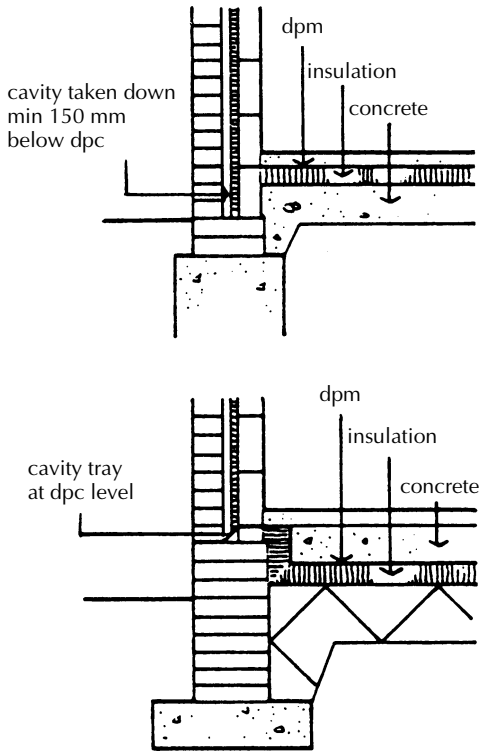
Figure 5.12 Damp-proof courses in cavity walls.

It is accepted practice to finish the cavity in external walling at the level of the dpc, at least 150 mm above ground. The wall is built as a solid wall up to the dpc, as illustrated in Figure 5.11, or the cavity below ground is filled with concrete to resist the ground pressure (Figure 5.13). With this arrangement the requirements of the Building Regulations recommend the use of a cavity tray at the bottom of the cavity. This tray takes the form of a sheet of a flexible, impermeable material such as one of the flexible dpc materials, which is laid across the cavity from a level higher in the inner leaf so that it falls towards the outer leaf to catch and drain any snow or moisture that might enter the cavity. The cavity thus acts as both tray and dpc to the cavity wall leaves.

5.3 Stone

Because natural stone is expensive it is mainly used as a facing material bonded or fixed to a backing of brickwork or concrete. Many of the larger civic and commercial buildings are faced with natural stone because of its durability, texture, colour and sense of permanence. Natural stone is also used as the outer
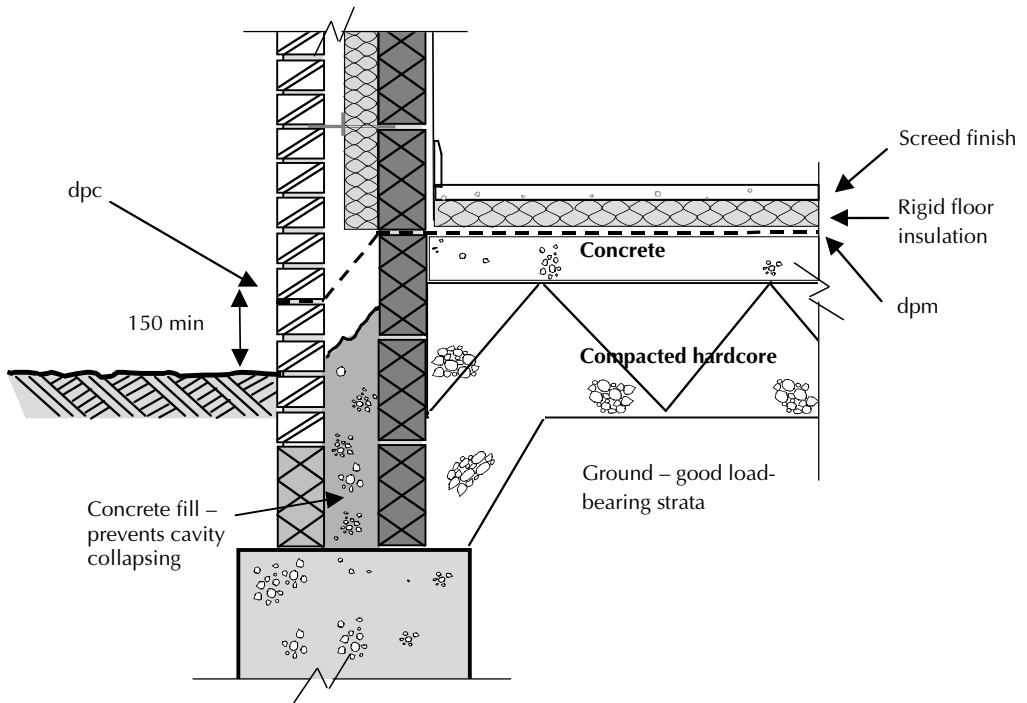
Figure 5.13   dpc – cavity tray.

leaf of cavity walls for houses (both loadbearing and framed construction) in areas where local quarries can supply stone at reasonable cost. Much of the time consuming and therefore expensive labour of cutting, shaping and finishing building stone has been appreciably reduced by the use of power operated tools, edged or surfaced with diamonds. This facility has improved output in the continuing and extensive work of repair and maintenance to stone buildings and encourages the use of natural stone as a facing material for new buildings. Because natural stone is an expensive material, various artificial stone products have been developed as alternatives.

Natural stone

The natural stones used in building may be classified by reference to their origin as: (1) igneous, such as granite and basalt; (2) sedimentary, such as limestones and sandstones and (3) metamorphic, such as slates and marble. Natural stone has been used in the construction of buildings because it was thought that any hard, natural stone would resist the action of wind and rain for centuries. Many natural stones have been used in walling and have proved to be extremely durable for a hundred or more years. There have been some failures of natural

stone due to a poor selection of the material, poor workmanship and/or poor detailing. Variation within the stone may cause localised weathering problems on exposure to rain and chemical pollutants in the air.

Some natural stones are comparatively soft and moist when first quarried but gradually harden. Building stones should be seasoned (allowed to harden) for periods of up to a few years, depending on the size and type of the stones. Natural stones that are stratified, limestone and sandstone, must be used in walling so that they lie on their natural bed to support compressive stress. The bed of a stone is its face parallel to the strata (layer) of the stones in the quarry and the stress that the stone suffers in use should be at right angles to the strata or bed, which otherwise might act as a plane of weakness and give way under compressive stress. The stones in an arch are laid with the bed or strata radiating roughly from the centre of the arch so that the bed is at right angles to the compressive stress acting around the curve of the arch.

Reconstituted (reconstructed) stone

Cast stone is one of the terms used to describe concrete cast in moulds to resemble blocks of natural stone. When the material first came into use it was called artificial stone. To avoid the use of the pejorative term artificial, the manufacturers now prefer the description reconstructed or reconstituted stone; 'Art' stone is another widely used term.

Reconstructed stone is made from an aggregate of crushed stone, cement and water. The stone is crushed so that the maximum size of the particles is 6 mm and it is mixed with cement in the proportions of one part cement to three or four parts of stone. Portland cement, white cement or coloured cement may be used to simulate the colour of a natural stone as closely as possible. A comparatively dry mix of cement, crushed stone and water is prepared and cast in moulds. The mix is thoroughly consolidated inside the moulds by vibrating and left to harden in the moulds for at least 24 hours. The stones are then taken out of the moulds and allowed to harden gradually for 28 days.

Well-made reconstructed stone has much the same texture and colour as the natural stone from which it is made and can be cut, carved and dressed just like natural stone. It is not stratified, is free from flaws and is sometimes a better material than the natural stone from which it is made. Moulded cast stones made by repetitive casting can often be produced more cheaply than similar natural stones that have to be cut and shaped.

A cheaper form of cast stone is made with a core of ordinary concrete, faced with an aggregate of crushed natural stone and cement. This material should more properly be called cast concrete. The core is made from clean gravel, sand and cement and the facing is made from crushed stone and cement to resemble the texture and colour of a natural stone. The crushed stone, cement and water is first spread in the base of the mould to a thickness of about 25 mm, the core concrete is added and the mix consolidated. If the stone is to be exposed on

two or more faces the natural stone mix is spread up the sides and the bottom of the mould. This type of cast stone cannot be carved as it has only a thin surface of natural looking stone.

As an alternative to a facing of reconstructed stone, the facing or facings can be made of cement and sand pigmented to look somewhat like the colour of a natural stone. Cast stones made with a surface skin of material to resemble stone do not usually weather in the same way that natural stone does, by a gradual change of colour. The material tends to have a lifeless, mechanical appearance and may in time tend to show irregular, unsightly dirt stains at joints, cracks and around projections. Reconstructed stone is used as an ashlar facing to brick or block backgrounds for both solid walls, the outer leaf of cavity walls and also as facings.

Functional requirements of stone

Strength and stability
The strength of sound building stone lies in its very considerable compressive strength. The ultimate or failing stress of stone used for walling is about 300 to $100 \, N/mm^3$ for granite, 195 to $27 \, N/mm^3$ for sandstone and 42 to $16 \, N/mm^3$ for limestone. The use of stone as a facing material makes little use of the inherent compressive strength of the material. The strength and stability of a stone wall is affected by the same limitations that apply to walls of brick or block.

Resistance to weather and ground moisture
To prevent moisture rising from the ground through foundation walls it is necessary to form a continuous horizontal dpc some 150 mm above ground level. Historically this was achieved using dense stone, such as granite, that does not readily absorb moisture, or a thin sheet lead dpc; today a thin strip of reinforced plastic is used. The resistance to the penetration of wind driven rain was not generally a consideration in the construction of solid masonry walls. The very considerable thickness of masonry walls of traditional large buildings was such that little, if any, rain penetrated to the inside face.

With the use of stone largely as a facing material it is necessary to construct walls faced with stone as cavity walling with a brick or block inner leaf separated by a cavity, as illustrated in Figure 5.14. The outer leaf illustrated is built with natural stone blocks bonded to a brick backing, with full width stones in every other course and the stones finished on face in ashlar masonry. This is an expensive form of construction because of the considerable labour costs in preparing the stones. As alternatives, the outer leaf of small buildings may be constructed with stone blocks for the full thickness of the outer leaf or, with larger buildings, the outer leaf may be constructed of brick to which a facing of stone slabs is fixed.

coping stone

lead dpc

timber framed
pitched roof
covered with
slates

lead lined taper gutter

1 B thick
outer leaf of
cavity wall
faced with
ashlared
stones
bonded to
brick
backing in
alternate
courses.
Stones are
1B and
$1/2$ B on
bed

$1/2$ B inner leaf,
cavity filled with
insulation

timber floor built
into inner leaf

wood casement
window

lead dpc

ground supported
solid floor

Figure 5.14   Cavity wall faced with ashlared stone and brick backing.

Ashlar walling is constructed of blocks of stone that have been very accurately cut and finished true square to specified dimensions so that the blocks can be laid, bedded and bonded with comparatively thin mortar joints, as illustrated in Figure 5.14. The very considerable labour involved in cutting and finishing individual stones is such that this type of walling is very expensive. Ashlar walling has been used for the larger, more permanent buildings and is now used principally as a facing material.

Durability and freedom from maintenance

Sound natural stone is highly durable as a walling material and will have a useful life of very many years in buildings that are adequately maintained. Granite, for example, is resistant to all usual weathering agents, including highly polluted atmospheres, and will maintain a high natural polished surface for a hundred years or more. Hard sandstones are very durable and inert to weathering agents but can stain over time, due to the coarse grained texture of the material, which retains dirt particles. The surface of sandstone may be cleaned from time to time to remove dirt stains by abrasive blasting with grit or chemical processes and thorough washing.

Sound limestone, sensibly selected and carefully laid, is durable for the anticipated life of the majority of buildings. In time the surface weathers by a gradual change of colour over many years. This is commonly held to be an advantage from the point of view of appearance. Limestones are soluble in rainwater that contains carbon dioxide so that the surface of a limestone wall is to an extent self-cleansing when freely washed by rain, while protected parts of the wall will collect and retain dirt. This effect gives the familiar black and white appearance of limestone masonry. The surface of limestone walls may be cleaned by washing with a water spray or by steam and brushing to remove dirt encrustations and the surface brought back to something near its original appearance.

Fire resistance

Natural stone is incombustible and will not support or encourage the spread of flame. The requirements of Part B of Schedule 1 to the Building Regulations for structural stability and integrity and for concealed spaces apply to walls of stone as they do for walls of block or brick masonry.

Resistance to the passage of heat

The natural stones used for walling are poor insulators against the transfer of heat and will contribute little to the thermal resistance in a wall. It is necessary to use some material with a low U value as cavity insulation in walls faced with stone in the same way that insulation is used in cavity walls of brick or blockwork.

Resistance to the passage of sound

Because natural building stone is dense it has good resistance to the transmission of airborne sound, but will provide a ready path for impact sound. Dense material will absorb sound energy and the sound energy should diminish quickly as it attempts to travel through the dense material.

5.4 Stone masonry walls

Openings to stone walls

Masonry over door and window openings may be supported by flat stone lintels or by segmental or semi-circular arches.

Lintels

A stone lintel for small openings of up to about a metre wide can be formed of one whole stone with its ends built into jambs and its depth corresponding to one or more stone courses. The poor tensile strength of stone limits the span of single stone lintels unless they are to be disproportionately deep. Over openings wider than about a metre it is usual to form lintels with three or five stones cut in the form of a flat arch. The stones are cut so that the joints between the ends of stones radiate from a common centre so that the centre, or key stone, is wedge-shaped, as illustrated in Figure 5.15. The stones are cut so that the lower face of each stone occupies a third or a fifth of the width of the opening.

To prevent the key stone sinking due to settlement and so breaking the line of the soffit, it is usual to cut half depth joggles in the ends of the key stone to fit to rebates cut in the other stones. The joggles and rebates may be cut the full thickness of each stone and show on the face of the lintel or more usually the joggles and rebates are cut on the inner half of the thickness of stones as secret joggles, which do not show on the face, as illustrated in Figure 5.16. The depth of the lintel corresponds to a course height, with the ends of the lintel built in at jambs as end bearing. Stone lintels are used over both ashlar and rubble walling. The use of lintels is limited to comparatively small openings due to the tendency of the stones to sink out of horizontal alignment. For wider openings some form of arch is used.

Arches

A stone arch consists of stones specially cut so that the joints between stones radiate from a common centre; the soffit is arched and the stones bond in with the surrounding walling. The individual stones of the arch are termed 'voussoirs', the arched soffit the 'intrados' and the upper profile of the arch stones the 'extrados', see Figure 5.15. The voussoirs of the segmental arch are cut with steps that correspond in height with stone courses, to which the stepped
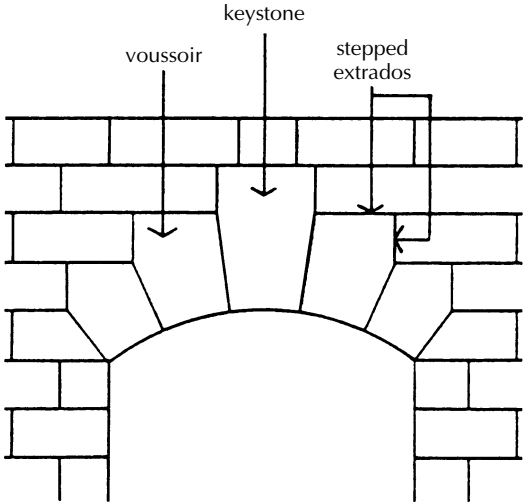
Figure 5.15   Segmental stone arch.
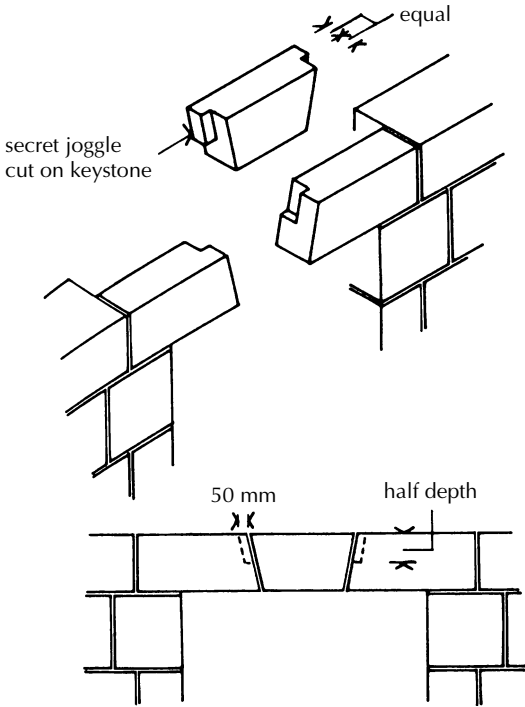
Figure 5.16   Stone lintel with secret joggle joints.
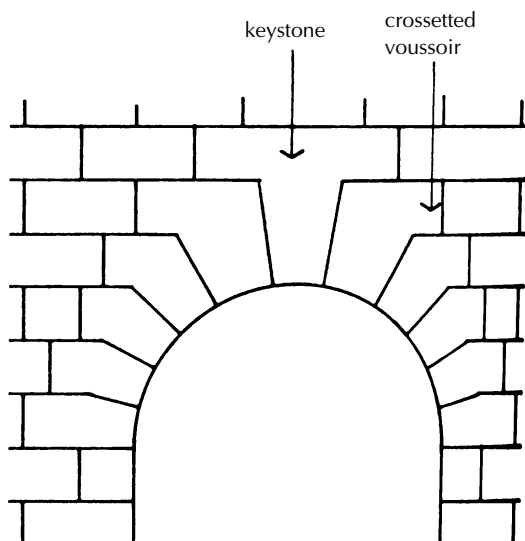
Figure 5.17   Semi-circular stone arch with crossetted voussoirs.

extrados is bonded. The stones of an arch are cut so that there are an uneven number of voussoirs with a centre or key stone. The key stone is the last stone to be put in place as a key to the completion and the stability of the arch, hence the term key stone.

Crossetted arch

The semi-circular arch, illustrated in Figure 5.17, is formed with stones that are cut to bond into the surrounding walling to form stepped extrados and also to bond horizontally into the surrounding stones. The stones, voussoirs, are said to be crossetted, or crossed. The stones radiate from a common centre with an odd number of stones arranged around the half circle so that there is a central key stone. The extent that the crossetted top of each stone extends into the surrounding masonry is not necessarily dictated by the stretcher bond of the main walling. Any degree of bond into the main wall may be chosen and the bond of masonry adjusted accordingly. The effect of the crossetted voussoir is to emphasise the arch as structurally separate from the coursed masonry and is chosen for that effect. There is some waste involved in cutting stones to achieve this effect.

Ashlar masonry joints

Ashlar stones may be finished with smooth faces and bedded with thin joints, or the stones may have their exposed edges cut to form a channelled or V joint to emphasise the shape of each stone and give the wall a heavier, more permanent appearance. The ashlar stones of the lower floor of large buildings are often

rebate cut on top
and one side edge of
each stone to form
channelled joint

V joints formed by cutting
edges of stones at 45°

40

channelled joints

V and channelled joints formed by
cutting rebate on edge of stones

(A) Channelled joint
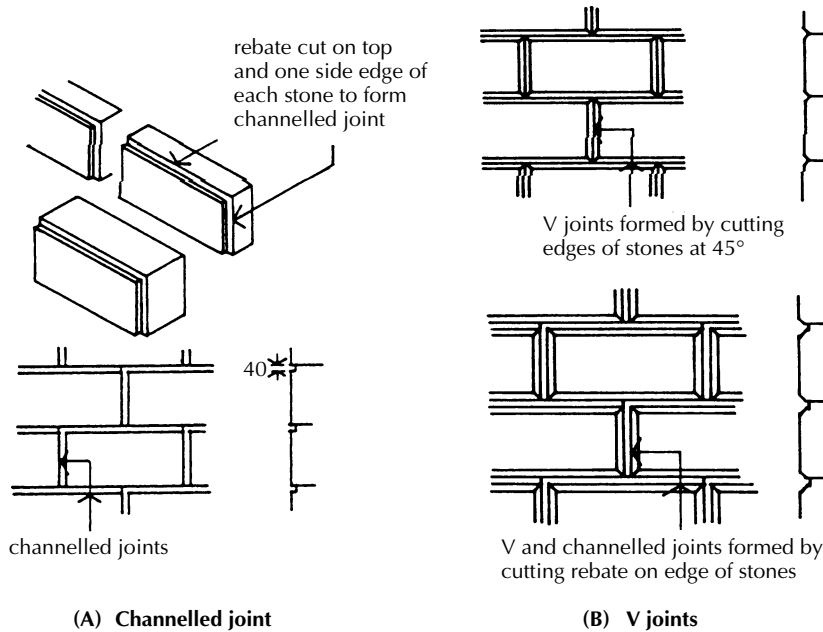
(B) V joints

Figure 5.18   (A) Channelled joint. (B) V joint.

finished with channelled or V joints and the wall above with plain ashlar masonry to give the base of the wall an appearance of strength. Ashlar masonry finished with channelled or V joints is said to be rusticated. A channelled joint (rebated joint) is formed by cutting a rebate on the top and one side edge of each stone, so that when the stones are laid, a channel rebate appears around each stone, as illustrated in Figure 5.18A. The rebate is cut on the top edge of each stone so that when the stones are laid rainwater, which may run into the horizontal joint, will not penetrate the mortar joint. A V joint (chamfered joint) is formed by cutting all four edges of stones with a chamfer so that when they are laid a V groove appears on face, as illustrated in Figure 5.18B. Often the edges of stones are cut with both V and channelled joints to give greater emphasis to each stone.

Tooled finish
Plain ashlar stones are usually finished with flat faces to form plain ashlar facing. The stones may also be finished with their exposed faces tooled to show the texture of the stone. Some of the tooled finishes used with masonry are illustrated in Figure 5.19. It is the harder stones such as granite and hard sandstone that are more commonly finished with rock face, pitched face, reticulated or vermiculated faces. The softer, fine grained stones are usually finished as plain ashlar.
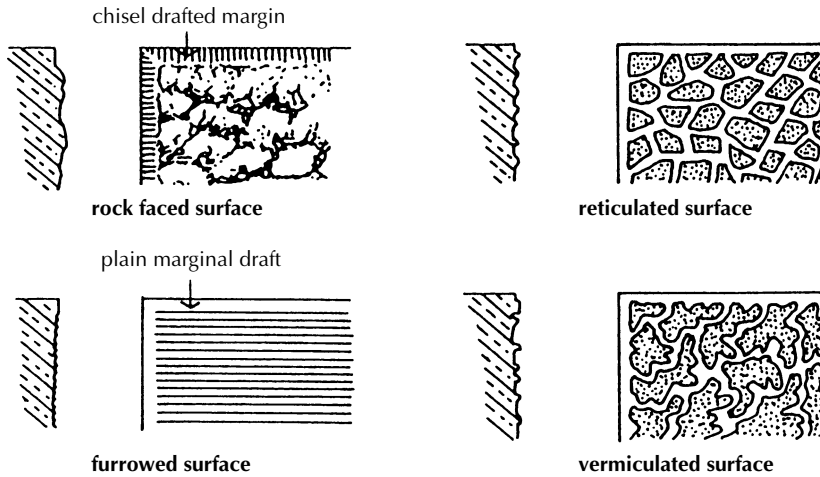
Figure 5.19   Tooled finishes.

Cornice and parapet walls

It is common practice to raise masonry walls above the levels of the eaves of a roof, as a parapet. The purpose of the parapet is partly to obscure the roof and also to provide a depth of wall over the top of the upper windows for the sake of appearance in the proportion of the building as a whole. In order to provide a decorative termination to the wall, a course of projecting moulded stones is formed. This projecting stone course is termed a cornice and it is generally formed of one or more courses of stone below the top of the parapet. Figure 5.20
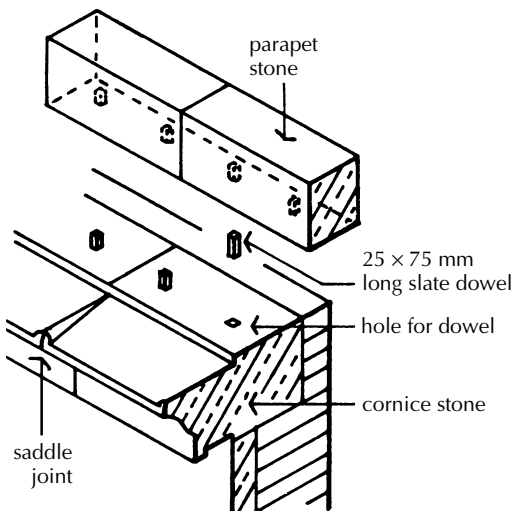
Figure 5.20   Cornice and parapet.

is an illustration of a cornice and a parapet wall to an ashlar faced building. An advantage of the projecting cornice is that it affords some protection against rain to the wall below.

The parapet wall usually consists of two or three courses of stones capped with coping stones bedded on a dpc of sheet metal. The parapet is usually at least one B thick or of such thickness that its height above the roof is limited by the requirements of the Building Regulations. The parapet may be built of solid stone or stones bonded to a brick backing. The cornice is constructed of stones of about the same depth as the stones in the wall below, cut so that they project and are moulded for appearance sake. Because the stones project, their top surface is weathered (slopes out) to throw water off.

Saddle joint

The projecting, weathered top surface of coping stones is exposed and rain running off it will in time saturate the mortar in the vertical joints between the stones. To prevent rain soaking into these joints it is usual to cut the stones to form a saddle joint as illustrated in Figure 5.20. The exposed top surface of the stones has to be cut to slope out (weathering) and when this cutting is executed a projecting quarter circle of stone is left on the ends of each stone. When the stones are laid, the projections on the ends of adjacent stones form a protruding semi-circular saddle joint, which causes rain to run off away from the joints.

Weathering to cornices

Because cornices are exposed and liable to saturation by rain and possible damage by frost, it is good practice to cover the exposed top surface of cornice stones cut from limestone or sandstone with sheet metal. The sheet metal covering is particularly useful in urban areas where airborne pollutants may gradually erode stone. Sheet lead is preferred as a non-ferrous covering because of its ductility, which facilitates shaping, and its impermeability. Sheets of lead, code No. 5, are cut and shaped for the profile of the top of the cornice, and laid with welted (folded) joints at 2 m intervals along the length of the cornice. The purpose of these comparatively closely spaced joints is to accommodate the inevitable thermal expansion and contraction of the lead sheet. The top edge of the lead is dressed up some 75 mm against the parapet as an upstand, and turned into a raglet (groove) cut in the parapet stones and wedged in place with lead wedges. The joint is then pointed with mortar. The bottom edge of the lead sheets is dressed (shaped) around the outer face of the stones and welted (folded). To prevent the lower edge of the lead sheet weathering being blow up in high winds, 40 mm wide strips of lead are screwed to lead plugs set in holes in the stone at 750 mm intervals, and folded into the welted edge of the lead, as illustrated in Figure 5.21. Where cornice stones are to be protected with sheet lead weathering there is no purpose in cutting saddle joints.

welted expansion joints
at 2.0 m intervals

75 mm upstand
turned into raglet

code No 5 sheet
lead weathering
to cornice

40 mm wide lead
tacks screwed to plug
in stone at 750 mm
intervals

drip edge of
lead welted
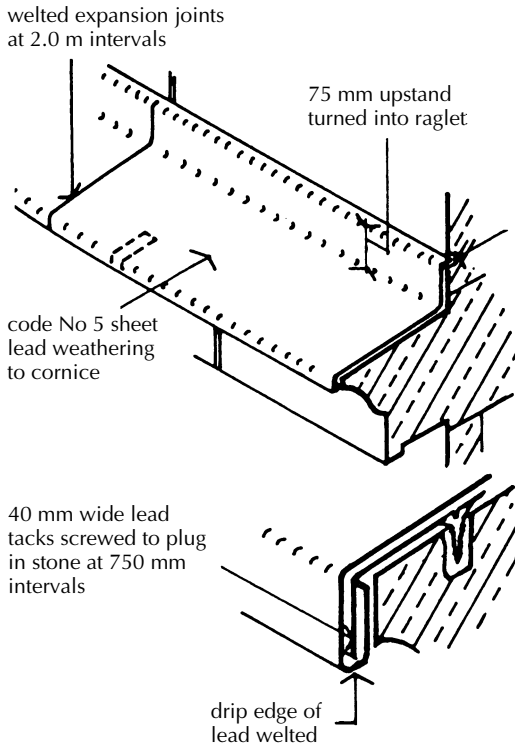
Figure 5.21   Lead weathering to cornice.

Cement joggle

Cornice stones project and one or more stones might in time settle slightly so that the decorative line of the mouldings cut on them would be broken and so ruin the appearance of the cornice. To prevent this possibility, shallow V-shaped grooves are cut in the ends of each stone so that when the stones are put together these matching V grooves form a square hole into which cement grout is run. When the cement hardens it forms a joggle, which locks the stones in their correct position.

Dowels

To maintain parapet stones in their correct position in a wall, slate dowels are used. The stones in a parapet are not kept in position by the weight of walling above and these stones are, therefore, usually fixed with slate dowels. These dowels consist of square pins of slate that are fitted to holes cut in adjacent stones, as illustrated in Figure 5.20.

(A)   Slate cramp   **(B)   Metal cramp**
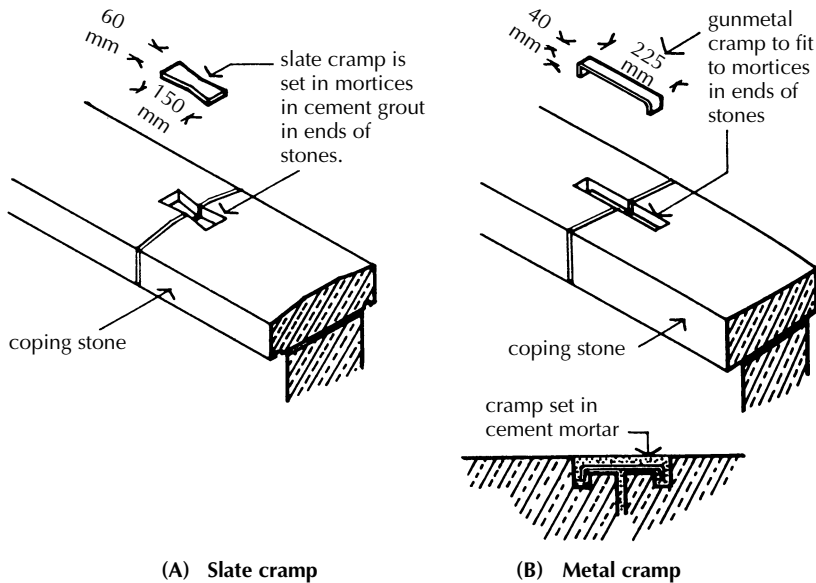
Figure 5.22   (A) Slate cramp. (B) Metal cramp.

Cramps

Coping stones are bedded on top of a parapet wall as a protection against water soaking down into the wall below. There is a possibility that the coping (capping) stones may suffer some slight movement and cracks in the joints between them open up. Rain may then saturate the parapet wall below and frost action may contribute to some movement and eventual damage. To keep coping stones in place a system of cramps is used. Either slate or non-ferrous metal is used to cramp the stones together. A short length of slate, shaped with dovetail ends, is set in cement grout (cement and water) in dovetail grooves in the ends of adjacent stones, as illustrated in Figure 5.22A. As an alternative, a gunmetal cramp is set in a groove and mortice in the end of each stone and bedded in cement mortar, as illustrated in Figure 5.22B. For coping stones cut from limestone or sandstone a sheet metal weathering is sometimes dressed over coping stones. The weathering of lead is welted and tacked in position over the stones.

Types of walling

Rubble walling

Rubble walling has been extensively used for agricultural buildings in towns and villages in those parts of the country where a local source of stone was readily available. The various forms of rubble walling may be classified as random rubble and squared rubble.
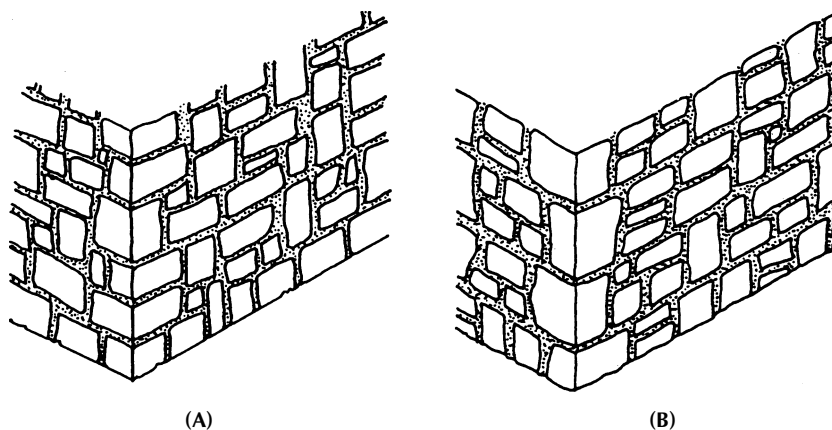
Figure 5.23   Random rubble uncoursed (A) and coursed (B).

Random rubble

Uncoursed random rubble stones of all shapes and sizes are selected more or less at random and laid in mortar, as illustrated in Figure 5.23A. No attempt is made to select and lay stones in horizontal courses. There is some degree of selection to avoid excessively wide mortar joints and also to bond stones by laying some longer stones both along the face and into the thickness of the wall, so that there is a bond stone in each square metre of walling. At quoins, angles and around openings selected stones or shaped stones are laid to form roughly square angles.

Random rubble brought to course is similar to random rubble uncoursed except that the stones are selected and laid so that the walling is roughly levelled in horizontal courses at vertical intervals of from 600 to 900 mm, as illustrated in Figure 5.23B. As with uncoursed rubble, transverse and longitudinal bond stones are used.

Squared rubble

Squared rubble uncoursed is laid with stones that come roughly square from the quarry in a variety of sizes. The stones are selected at random, are roughly squared with a walling hammer and laid without courses, as illustrated in Figure 5.24A. As with random rubble, both transverse and longitudinal bond stones are laid at intervals. Snecked rubble is a term for squared rubble in which a number of small squared stones, snecks, are laid to break up long continuous vertical joints. Snecked rubble is often difficult to distinguish from squared random rubble.

Squared rubble brought to course is constructed from roughly square stone rubble, selected and squared so that the work is brought to courses every 300 to 900 mm intervals, as illustrated in Figure 5.24B. Squared rubble coursed is
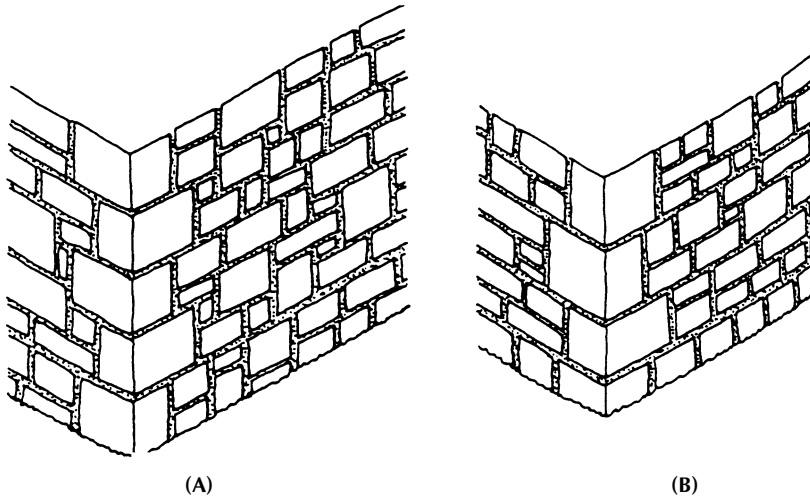
Figure 5.24   (A) Squared rubble uncoursed. (B) Squared rubble coursed.

built with stones that are roughly squared so that the stones in each course are roughly the same height and the courses vary in height, as illustrated in Figure 5.25A. The face of the stones may be roughly dressed to give a rock-faced appearance or dressed smooth to give a more formal appearance.

Polygonal walling
Stones that are taken from a quarry where the stone is hard, have no pronounced laminations and come in irregular shapes that can be laid as polygonal walling.
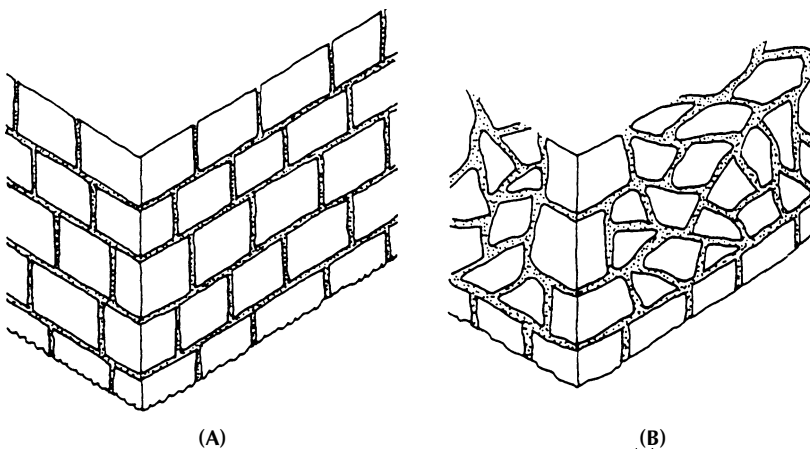
Figure 5.25   (A) Squared rubble coursed. (B) Polygonal walling.
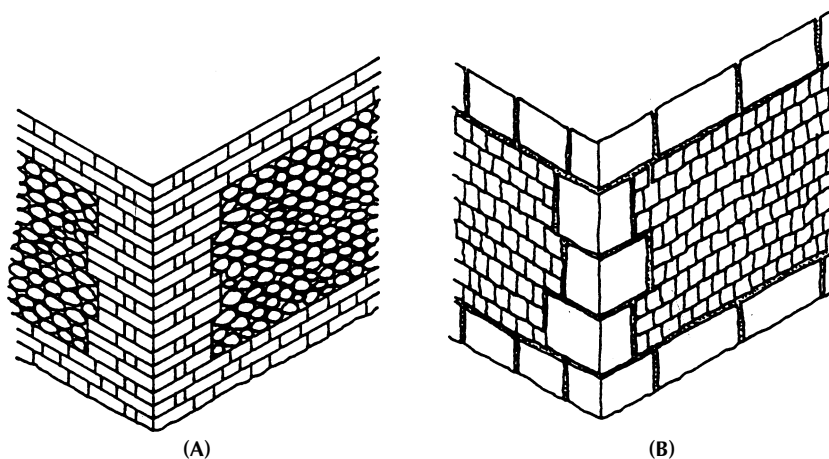
Figure 5.26   (A) Whole flint wall. (B) Knapped flint wall.

The stones are selected and roughly dressed to fit when laid, to an irregular pattern, with no attempt at regular courses or vertical joints. At corners and as a base, roughly square edged stones are used, as illustrated in Figure 5.25B.

Flint walling
Flint walling is traditional to East Anglia and the south and south-east of England. Both field and shore flints are used. The flints used for walling are up to 300 m in length and from 75 to 250 mm in width and thickness. The flints or cobbles may be used whole or split to show the heart of the flint, and also knapped or snapped so that they show a roughly square face. Flint walling is built with a dressing of stone or brick at angles and in horizontal lacing courses that level the wall at intervals. Figure 5.26A is an illustration of whole flints laid without courses in brick dressing to angles and as lacing and Figure 5.26B an illustration of knapped flints laid to courses in stone dressing. Rubble walling is generally considerably thicker than a wall of square bricks or blocks because of the inherent instability of a wall built of irregular shaped blocks. Rubble walling for buildings is usually at least 400 mm thick.

5.5 Bricks and brickwork

The word 'brick' is used to describe a small block of burned clay of such size that it can be conveniently held in one hand and it is slightly longer than twice its width. The great majority of bricks in use today are made from clay,

Standard brick

Fletton brick showing kiss marks

215 mm

102.5 mm

65 mm

two bands of
darker colour

frog or indent

dovetail grooves
on two faces only

Keyed Fletton

perforated brick

cellular pressed brick

Cellular and perforated bricks.
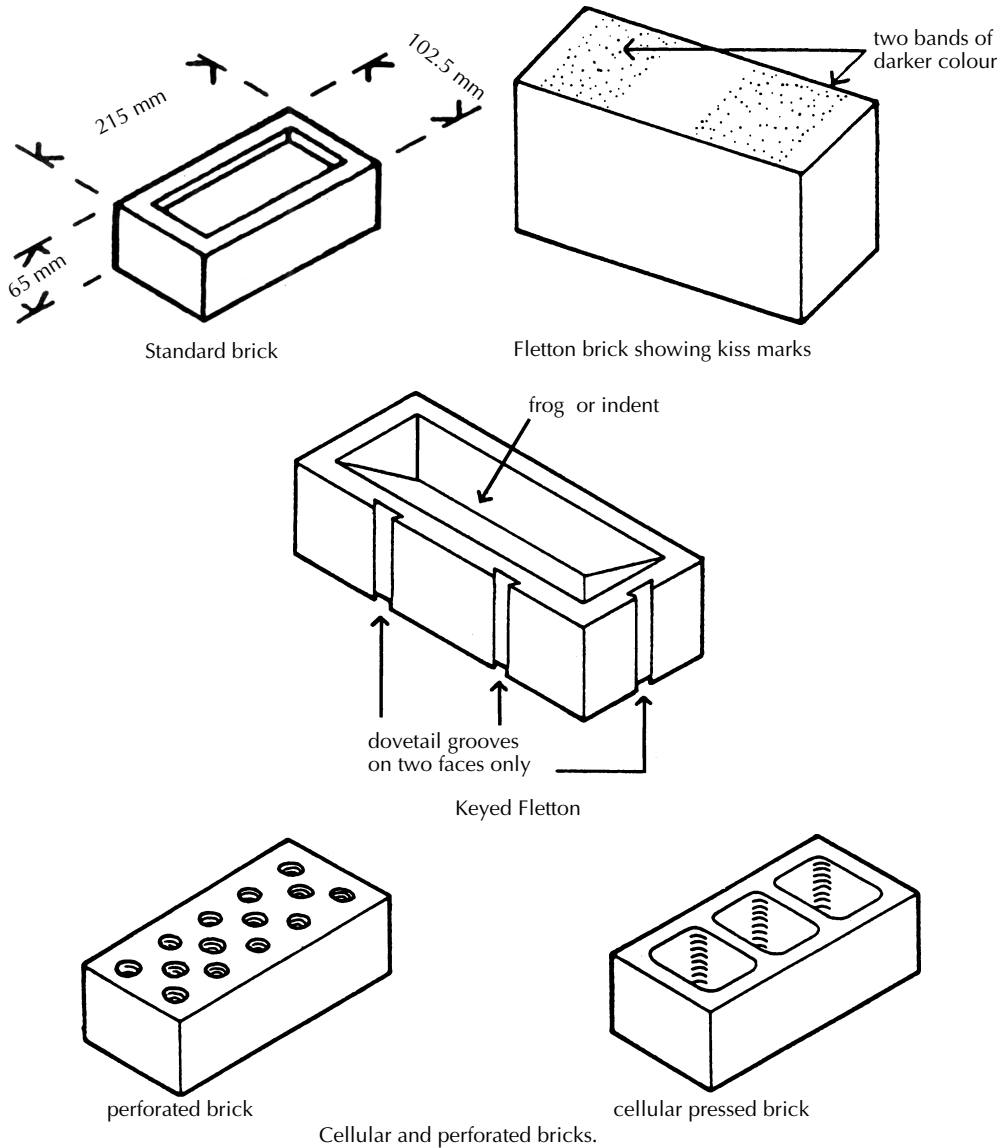
Figure 5.27   Types of brick.

although bricks can also be made from sand and lime or concrete. Glass bricks
and blocks are also widely available. In the UK the standard brick size is
$215 \times 102.5 \times 65$ mm, as illustrated in Figure 5.27. With a 10 mm mortar joint
the working size becomes $225 \times 112.5 \times 75$ mm. Bricks may be manufactured
to other shapes and sizes and are usually known as 'specials'.

Types of brick

Clay bricks

Clay differs quite widely in composition from place to place and the clay dug from one part of a field may differ from that dug from another part of the same field. Clay is ground in mills, mixed with water to make it plastic and then moulded, either by hand or machine, to the shape and size of a brick. Bricks that are shaped and pressed by hand in a sanded wood mould and then dried and fired have a sandy texture, are irregular in shape and colour and are used as facing bricks due to the variety of their shapes, colour and texture. Machine made bricks are either hydraulically pressed in steel moulds or extruded as a continuous band of clay. The continuous band of clay, the section of which is the length and width of a brick, is cut into bricks by a wire frame. Bricks made this way are called 'wire cuts'. The moulded brick is baked to dry out the water and burned at a high temperature so that part of the clay fuses the whole mass of the brick into a hard durable unit. Because there is wide variation in the composition of the clays suitable for brick making, and because it is possible to burn bricks over quite a wide range of temperatures sufficient to fuse the material into a durable mass, a large variety of bricks is available.

Calcium silicate bricks (sand-lime)

Calcium silicate bricks are generally known as sand-lime bricks. The bricks are made from a carefully controlled mixture of clean sand and hydrated lime which is mixed together with water, heavily moulded to brick shape and then the moulded brick is hardened in a steam oven. The resulting bricks are very uniform in shape and colour and are normally a dull white. Coloured sand-lime bricks are made by adding a colouring matter during manufacture. The material from which they are made can be carefully selected and accurately proportioned to ensure a uniform hardness, shape and durability that is quite impossible with the clay used for most bricks.

Concrete bricks

Concrete bricks are manufactured in the same size as clay bricks. They tend to be more consistent in shape, size and colour than clay bricks and come in a variety of colours and finishes. Appearance and properties vary between manufacturers, although the concrete brick does have a different appearance from clay bricks, which extends the choice to the designer.

Brick classifications

Bricks may be classified in accordance with their uses as commons, facing and engineering bricks, although they should be specified according to performance requirements, i.e. strength, thermal performance, water absorption, etc.

Commons

These are bricks that are sufficiently hard to carry the loads normally supported by brickwork safely, but because they have a dull texture or are a poor colour they are not in demand for use as facing bricks. Commons are used for internal walls that are not usually exposed to view.

Facings

This includes any brick that is sufficiently hard burned to carry normal loads, is capable of withstanding the effects of rain, wind, soot and frost without breaking up and that is thought to have a pleasant appearance. As there are as many different ideas of what is a pleasant looking brick as there are bricks produced, this is a somewhat vague classification.

Engineering bricks

These are bricks that have been made from selected clay, that have been carefully prepared by crushing, have been very heavily moulded and carefully burned so that the finished brick is very solid and hard and is capable of safely carrying much heavier loads than other type of brick. These bricks are mainly used for walls carrying exceptionally heavy loads, for brick piers and general engineering works.

Special bricks

A range of special bricks are made for specific uses in fairface brickwork. These bricks are made from fine clays to control and reduce shrinkage deformation during firing. Figure 5.28 is an illustration of some typical (standard) specials. The two coping bricks, the half round and the saddleback, are for use as coping to a one brick thick parapet wall. The bricks are some 50 mm wider than the thickness of a one brick wall so that they overhang the wall each side to shed rainwater: the grooves on the underside of the hangover form a drip edge. The two bullnose specials are made as a capping or coping for one brick thick walls. They are of the same length as the thickness of the wall on which they are laid, to provide protection and a flush finish to the wall. The plinth bricks are used to provide and cap a thickening to the base of walls, a plinth. A plinth at the base of a wall gives some definition to the base of a wall as opposed to the wall being built flush out of the ground. A plinth may be formed by the junction of a solid $1\frac{1}{2}$ brick thick wall built from the foundation up to a cavity wall.

Special specials

Manufacturers also make purpose-made specials, known as 'special specials' to suit particular design requirements. Additional time will be needed to design and manufacture the special specials and this will need to be considered in the programming of the construction works. These bricks tend to be expensive because they are made to order and often made in small quantities.

half round coping

double bullnose

saddleback coping

bullnose double stretcher

plinth header

plinth stretcher
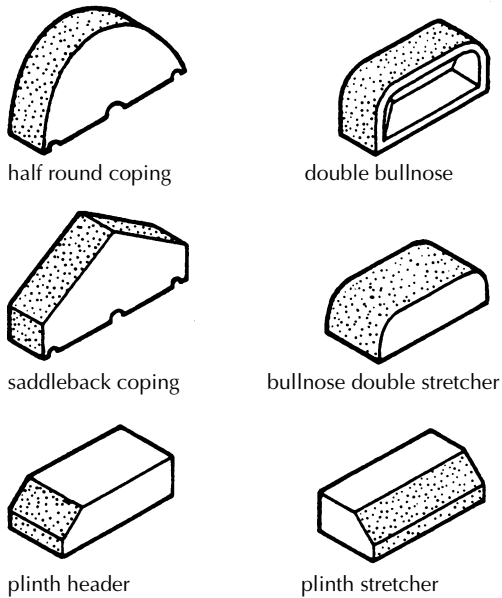
Figure 5.28   Special bricks.

However, used as a design feature, they can prove to add considerable value to brick walls.

Physical properties of bricks

When specifying bricks, certain properties need to be defined that relate to durability, form and appearance. A performance specification will need to consider the following parameters: size and type, compressive strength, frost resistance, soluble-salt content and visual appearance. It is common practice to specify facing bricks by name (manufacturer and brick name), which will automatically confirm the brick's characteristics, thus determining the exact appearance (colour and texture) required.

Compressive strength

The compressive strength of bricks is found by crushing twelve of them individually until they fail or crumble. The pressure required to crush them is noted and the average compressive strength of the brick is stated as newtons per mm of surface area required to ultimately crush the brick. The crushing resistance varies from about $3.5 \, \text{N/mm}^2$ for soft facing bricks up to $140 \, \text{N/mm}^2$ for engineering bricks.

Table 5.1   Thermal and moisture movement joints in brickwork.

Brick type	Type of movement	Recommended distance between joints (mm)
Clay fired bricks	Expansion	12
Calcium silicate bricks	Shrinkage	7.5–9
Concrete blocks or bricks	Shrinkage	6

Water absorption and suction

The amount of water a brick will absorb is a guide to its density and therefore its strength in resisting crushing. The level of water absorption is most critical for bricks to be used below dpc level or for damp-proof courses. Absorption rates vary between 1% and 35%. Bricks with high suction rates absorb water rapidly from the mortar and hence they are more difficult to reposition as the work proceeds than bricks with medium to low suction rates; suction rates are provided by brick manufacturers.

Thermal and moisture movement

All building materials move as a result of the expansion and contraction caused by temperature or moisture changes. The amount of movement depends on the materials and conditions, however allowance must be made for movement in masonry walls through careful positioning of control joints (BRE, 1985), see Table 5.1. Brick manufacturers offer guidance based on current Standards. The expansion in long walls without adequate control joints may result in the bricks at the end of the wall oversailing the dpc (Figure 5.29) or the corner of walls cracking (Figure 5.30).

For clay bricks it is recommended that the joint should be capable of accommodating 10 mm movement. Because materials will be used to construct

Expansion, caused by increases in moisture and heat, causes the bricks to expand. As they expand they may slide over the dpc.
When they shrink they do not always return to their original position and cracks may occur.

Bricks above the dpc may over sail the end of the wall.

Bricks below the dpc are more firmly held in place and retain their original position.
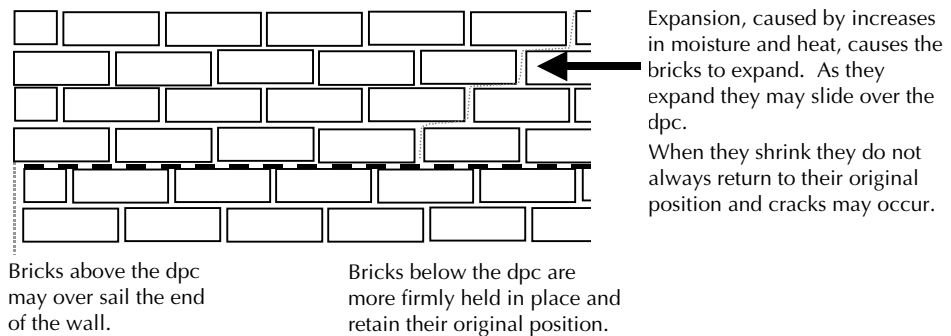
Figure 5.29   Elevation of a wall: Expansion of brickwork causing oversailing.

The potential for thermal or moisture movement to result in cracking is greater when returns in walls are short.

The short return in the wall means that all of the strain is exerted on the corner.

The wall expands and exerts considerable strain on corners.
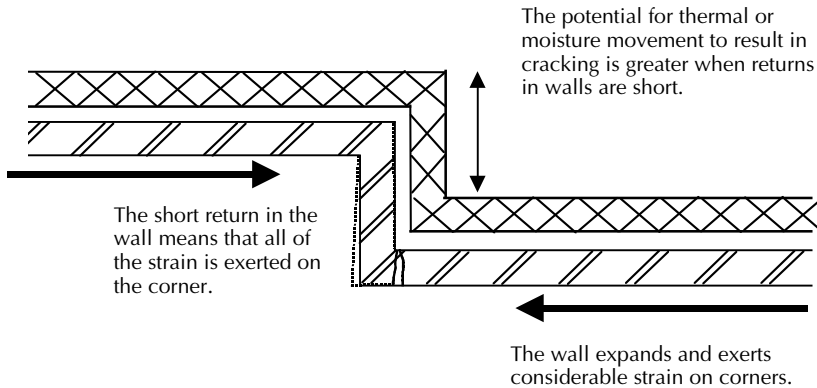
Figure 5.30   Plan of a wall junction: Expansion and shrinkage at corner joint.

and fill the joint this may mean that the joint is between 12 and 20 mm wide. Calcium silicate bricks suffer from contraction rather than expansion. Advice from the brick manufacturers should be sought. Where joints are used to accommodate shrinkage, the wall should be structurally sound when the joint is at its widest (when the wall has shrunk to its full extent). Movement joints should be located where there is lateral support (Figure 5.31).

Extra ties at 300 mm centres should be used each side of the joint. Wire and plastic wall ties can accommodate differential movement between the skins of cavity walls by bending and flexing. In some situations it may be necessary to place a wall tie directly across the movement joint. Specially designed sleeves can be used with straight wall ties: these allow for movement along the length of the ties, but resist movement in other directions (Figure 5.32).

Lateral support provided by returning wall

Compressible fill and flexible sealant

Wall ties at 300 mm vertical centres
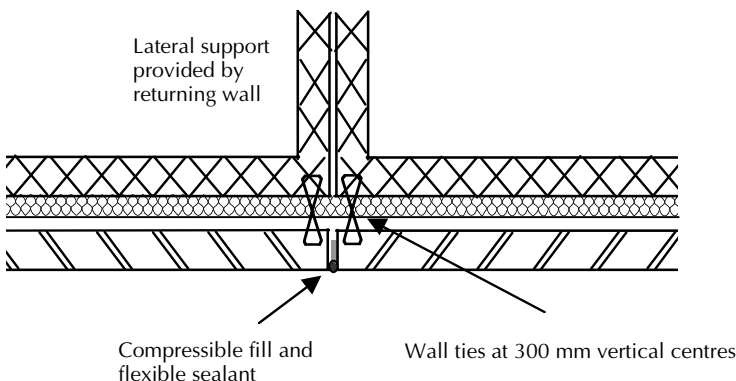
Figure 5.31   Lateral stability across movement joints provided by returning wall.
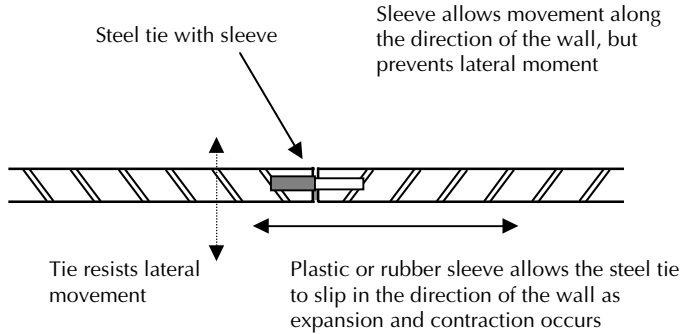
Figure 5.32 Lateral stability across movement joints provided by ties with sleeves.

Movement due to differential settlement

Where it is anticipated that differential settlement may occur due to different ground conditions, foundation designs or building loads, movement joints should be used to allow separate parts of the building to move without causing cracking to the facing or structural elements. In long buildings, or terraced housing it may be necessary to separate the buildings and incorporate movement joints that allow for differential settlement. The movement joints allow differential settlement while retaining the appearance of the building.

Appearance

There is a large choice of bricks from which to choose and choice is often made on personal preference for the colour and texture of the brick, assuming it meets the set performance standards. Choice is also influenced by that used on neighbouring buildings, local town planning authority requirements and the existing brick when working on repair and alteration works.

Frost resistance

If bricks are saturated and the water within them freezes (expanding as it freezes up to $-4\,°\text{C}$) it is likely that small cracks will develop, causing the face of the brickwork to break away (Photograph 5.1). Care is required in exposed areas, e.g. parapet walls, chimney stacks, around dpcs, in relation to the selection of bricks and the detailing of the respective junctions to ensure durability.

Efflorescence

Clay bricks contain soluble salts that migrate, in solution in water, to the surface of brickwork as water evaporates to outside air. These salts will collect on the face of brickwork as an efflorescence of white crystals that appear in irregular, unsightly patches. This efflorescence of white salts is most pronounced in parapet walls, chimneys and below dpcs where brickwork is most liable to saturation. The concentration of salts depends on the soluble salt content

Photograph 5.1   Face of brickwork removed by frost attack

of the bricks and the degree and persistence of saturation of brickwork. The efflorescence of white salts on the surface is generally merely unsightly and causes no damage. In time these salts may be washed from surfaces by rain. Heavy concentration of salts can cause spalling and powdering of the surface of bricks, particularly those with smooth faces. This effect is sometimes described as crypto efflorescence. The salts trapped behind the smooth face of bricks expand when wetted by rain and cause the face of the bricks to crumble and disintegrate. Efflorescence may also be caused by absorption of soluble salts from a cement rich mortar or from the ground. There is no way of preventing the absorption of soluble salts from the ground by brickwork below the horizontal dpc level, although the effect can be reduced considerably by the use of dense bricks below the dpc.

Sulphate attack on mortars and renderings
When brickwork is persistently wet, as in foundations, retaining walls, parapets and chimneys, sulphates in bricks and mortar may in time crystallise and expand and cause mortar and renderings to disintegrate. To minimise this effect bricks with low sulphate content should be used.

5.6 Bonding bricks

When building a wall it is usual to lay bricks in regular, horizontal courses so that each brick bears on two bricks below. The bricks are said to be 'bonded' since they bind together by being laid across each other along the length of the
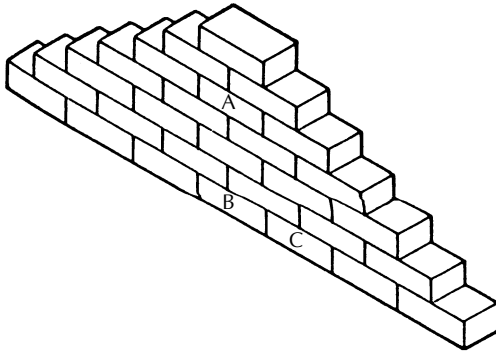
Figure 5.33   Bricks stacked pyramid fashion.

wall, as illustrated in Figure 5.33. The advantage of bonding is that the wall acts as a whole so that the load of a beam carried by the topmost brick is spread to the two bricks below it, then to the three below that and so on down to the base or foundation course of bricks. The failure of one poor quality brick such as 'A' in a wall and a slight settlement under part of the foundation such as 'B' and 'C' in Figure 5.33 will not affect the strength and stability of the whole wall as the load carried by the weak brick and the two foundation bricks is transferred to the adjacent bricks. Because of the bond, window and door openings may be formed in a wall, the load of the wall above the opening being transferred to the brickwork each side of the openings by an arch or lintel. The effect of bonding is to stiffen a wall along its length and also to some small extent against lateral pressure, such as wind.

Types of bond

Stretcher bond
The four faces of a brick, which may be exposed in fairface brickwork, are the two, long, stretcher faces and the two header faces illustrated in Figure 5.34.
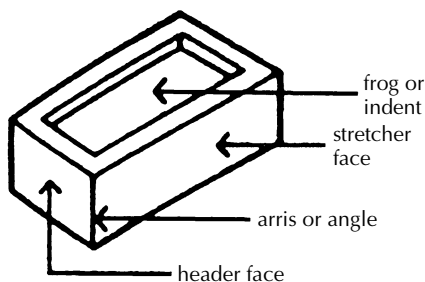
Figure 5.34   Brick faces.
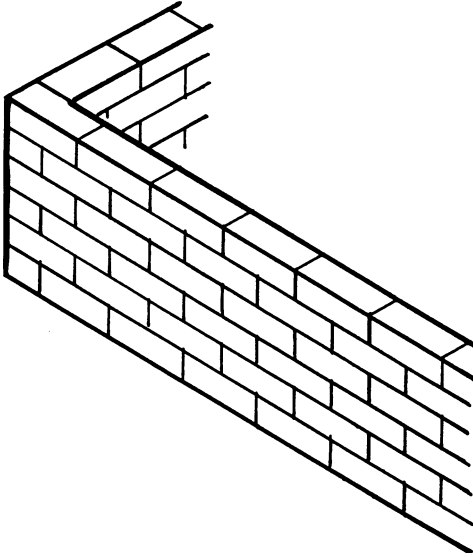
Figure 5.35   Stretcher bond.

The face on which the brick is laid is the bed. Some bricks have an indent or frog formed in one of the bed faces. The purpose of the frog or indent is to assist in compressing the wet clay during moulding. The frog also serves as a reservoir of mortar on to which bricks in the course above may more easily be bedded.
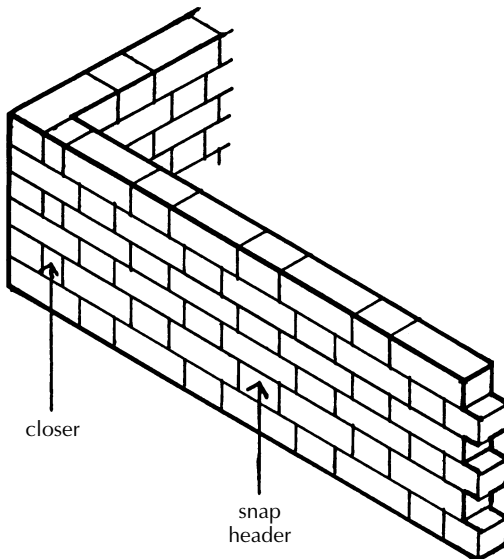
Figure 5.36   Flemish bond with snap headers.

A. Header bond

B. Flemish bond
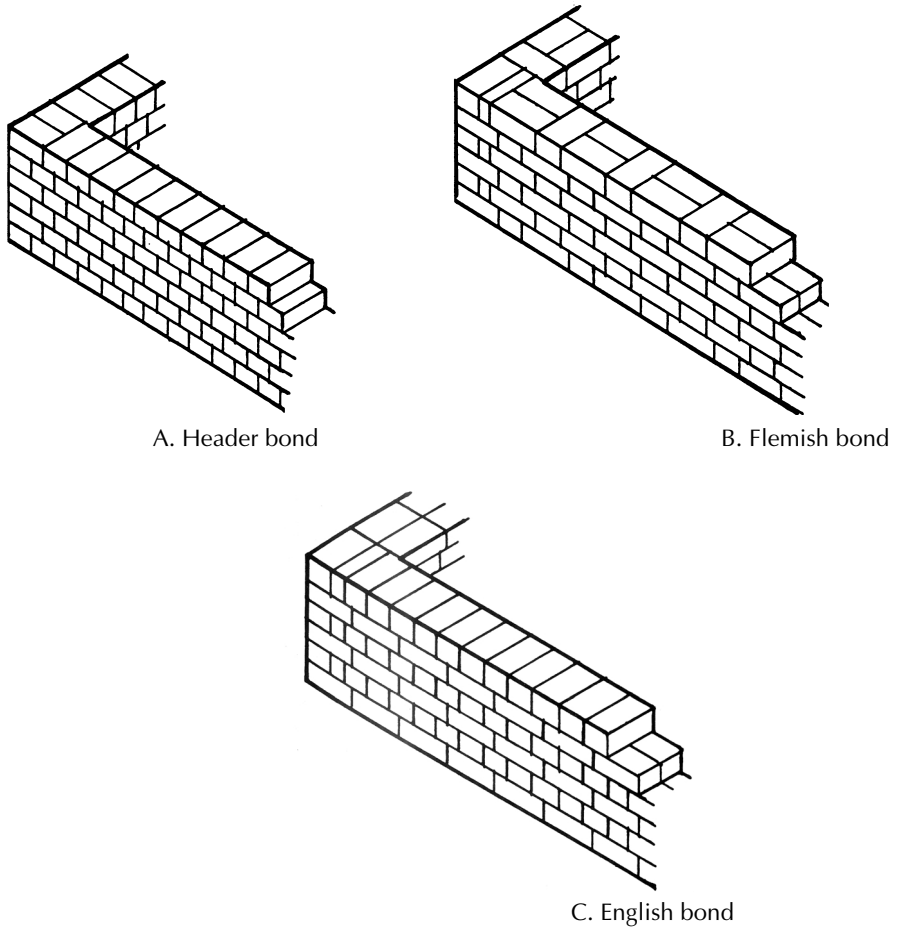
C. English bond

Figure 5.37 (A) Header bond. (B) Flemish bond. (C) English bond.

The length of bricks varies appreciably, especially those that are hand moulded and those made from plastic clays that will shrink differentially during firing. It has been practice for some time to describe the thickness of a wall by the length of a brick, i.e. $\frac{1}{2}$B, 1B, 1$\frac{1}{2}$B wall or a 2B wall, rather than a precise dimension (the wall in Figures 5.35 and 5.36 may be described as a $\frac{1}{2}$B thick wall and the walls in Figure 5.37 are described as 1B thick walls). This can cause confusion and dimensions should always be specified.

The external leaf of a cavity wall is often built of brick for the advantage of the appearance of brickwork. The most straightforward way of laying bricks in a thin outer leaf of a cavity wall is with the stretcher face of each brick showing externally. So that bricks are bonded along the length of the wall, they are laid with the vertical joints between bricks lying directly under and over the centre

of the bricks in the courses under and over. This is described as stretcher bond as illustrated in Figure 5.35.

At the intersection of two half brick walls at corners or angles and at the jambs, sides of openings, the bricks are laid so that a header face shows in every other course to complete the bond, as illustrated in Figure 5.35. The appearance of a wall laid in stretcher bond may look somewhat monotonous because of the mass of stretcher faces showing. To provide some variety the wall may be built with snap headers so that a stretcher face and a header face show alternately in each course with the centre of the header face lying directly under and over the centre of the stretcher faces in courses below and above, as illustrated in Figure 5.36. This form of fake Flemish bond is achieved by the use of half bricks, hence the name 'snap header'. The combination and variety in colour and shape can add appreciably to the appearance of a wall. Obviously the additional labour and likely wastage of bricks adds somewhat to cost.

English and flemish bond

For the same reason that a $\frac{1}{2}$B wall is bonded along its length, a solid wall 1B and thicker is bonded along its length and through its thickness. The two basic ways in which a solid brick wall may be bonded are with every brick showing a header face with each header face lying directly over two header faces below or with header faces centrally over a stretcher face in the course below. The bond in which header faces only show is termed 'heading' or 'header bond'. This bond is little used as the great number of vertical joints and header faces is generally considered unattractive. The bond in which header faces lie directly above and below a stretcher face is termed Flemish bond (Figure 5.37B). This bond is generally considered the most attractive bond for facing brickwork because of the variety of shades of colour between header and stretcher faces dispersed over the whole face of the walling.

English bond, illustrated in Figure 5.37C, avoids the repetition of header faces in each course by using alternate courses of header and stretcher faces with a header face lying directly over the centre of a stretcher face below. The colour of header faces may differ from the colour of stretcher faces. In English bond this difference is shown in successive horizontal courses. In Flemish bond the different colours of header and stretcher faces are dispersed over the whole face of a wall.

Bonding at angles and jambs

At the end of a wall at a stop end, at an angle or quoin and at jambs of openings the bonding of bricks has to be finished up to a vertical angle. To complete the bond a brick $\frac{1}{4}$B wide has to be used to close or complete the bond of the $\frac{1}{4}$B overlap of face brickwork. A brick, cut in half along its length, is used to close
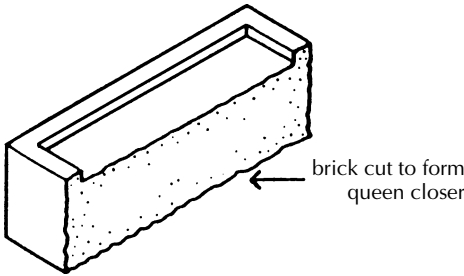
Figure 5.38   Queen closer.

the bond at an angle. This cut brick is termed a 'queen closer', illustrated in Figure 5.38. If the narrow width queen closer were laid at the angle, it might be displaced during bricklaying. To avoid this possibility the closer is laid next to a header, as illustrated in Figure 5.39. The rule is that a closer is laid next to a quoin (corner) header.

There is often an appreciable difference in the length of facing bricks so that a solid wall 1B thick may be difficult to finish as a wall 'fairface' both sides. The word fairface describes a brick wall finished with a reasonably flat and level face for the sake of appearance. Where a 1B wall is built with bricks of uneven length it may be necessary to select bricks of much the same length as headers
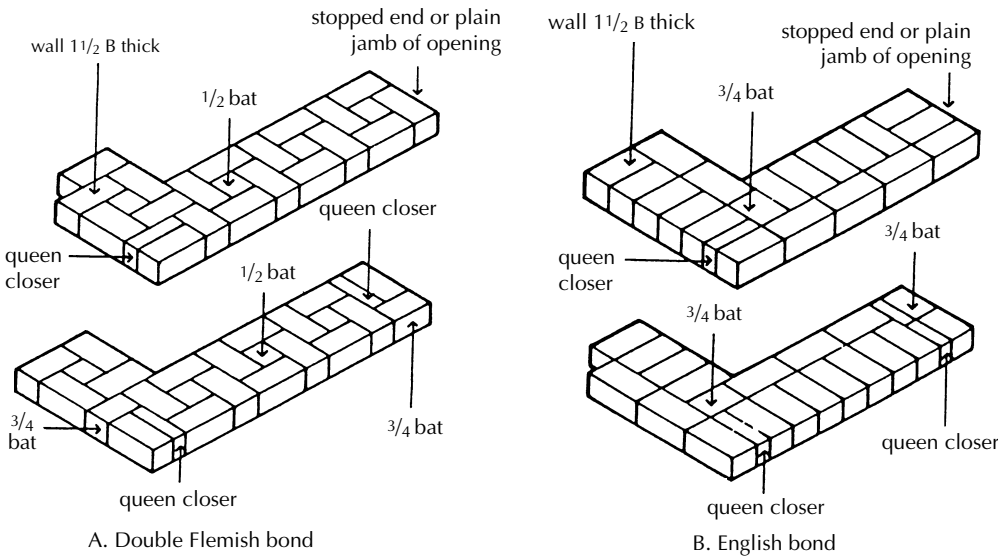
Figure 5.39   (A) Double Flemish bond. (B) English bond.

and use longer bricks as stretchers. Walls $1\frac{1}{2}$B thick may be used for substantial walling for larger buildings where the walling is finished fairface both sides.

To complete the bond of a solid wall $1\frac{1}{2}$B thick in double Flemish bond it is necessary to use cut half bricks in the thickness of the wall as illustrated in Figure 5.39A. At angles and stop ends of a wall, queen closers are laid next to quoin headers and a three quarter length cut brick is used. Cutting half-length ($\frac{1}{2}$ bats) and three quarter length bricks and closers is time consuming and wasteful. A $1\frac{1}{2}$B thick wall, finished fairface both sides and showing English bond both sides, requires considerably less cutting of bricks to complete the bond, as illustrated in Figure 5.39B. It is only necessary to cut closers and three quarter length bricks to complete the bond at angles and stop ends.

Garden wall bond

Garden wall bonds are designed specifically to reduce the number of through headers to minimise the labour in selecting bricks of roughly the same length for use as headers. Usual garden wall bonds are three courses of stretchers to every one course of headers in English garden wall bond and one header to every three stretchers in Flemish garden wall bond, as illustrated in Figure 5.39. The reduction in the number of through headers does to an extent weaken the through bond of the brickwork. Other combinations such as two or four stretchers to one header may be used. The tops of garden walls are finished with one of the special coping bricks illustrated in Figure 5.40 or a brick or stone capping or coping to provide weather protection to the top of the wall.
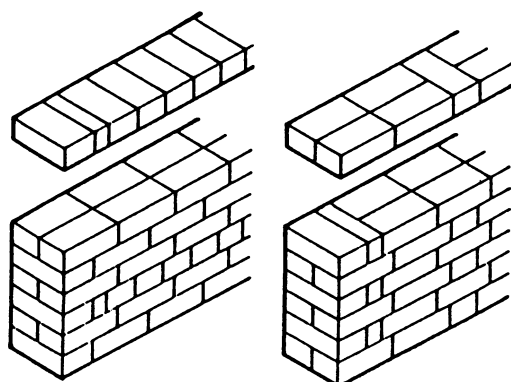
English garden wall bond   Flemish garden wall bond

Figure 5.40   Garden wall bonds.

5.7 Blocks and blockwork

Building blocks are wall units, larger in size than a brick, which can be handled by one person. Building blocks are made of concrete or clay.

Concrete blocks

These are used extensively for both loadbearing and non-loadbearing walls. A concrete block wall can be laid in less time and may cost up to half as much as a similar brick wall. Lightweight aggregate concrete blocks have good insulating properties against transfer of heat and are used for the inner leaf of cavity walls. Concrete blocks may be used as a fairface external wall finish. The blocks are accurately moulded to uniform sizes and made from aggregates to provide a variety of colours and textures. Blocks made to give an appearance of natural stone with plain or rugged exposed aggregate finish are also available.

Concrete blocks are manufactured from cement and either dense or lightweight aggregates as solid, cellular or hollow blocks as illustrated in Figure 5.41. A cellular block has one or more holes or cavities that do not pass wholly through the block and a hollow block is one in which the holes pass through the block. The thicker blocks are made with cavities or holes to reduce weight and drying shrinkage.

The most commonly used size of both dense and lightweight concrete blocks is 440 mm long × 215 mm high. The height of the block is chosen to coincide

solid blocks

cellular blocks
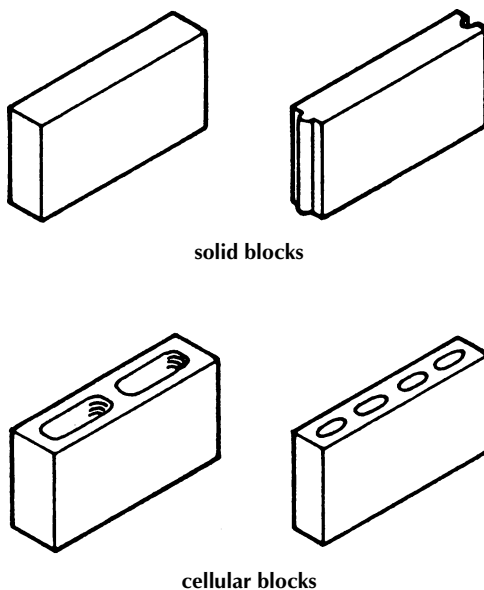
Figure 5.41   Concrete blocks.

with three courses of brick for the convenience of building in wall ties and also bonding to brickwork. The length of the block is chosen for laying in stretcher bond. For the leaves of cavity walls and internal loadbearing walls 100 mm thick blocks are used. For non-loadbearing partition walls 60 or 75 mm thick lightweight aggregate blocks are used. Either 440 mm × 215 mm or 390 × 190 mm blocks may be used. Concrete blocks may be specified by their minimum average compressive strength for:

❑   All blocks not less than 75 mm thick and
❑   A maximum average transverse strength for blocks less than 75 mm thick, which are used for non-loadbearing partitions.

The usual compressive strengths for blocks are 2.8, 3.5, 5.0, 7.0. 10.0, 15.0, 20.0 and 35.0 N/mm². The compressive strength of blocks used for the walls of small buildings of up to three storeys, recommended in Approved Document A is 2.8 and 7 N/mm², depending on the loads carried. Concrete blocks may also be classified in accordance with the aggregate used in making the block and some common uses.

Dense aggregate blocks for general use

The blocks are made of cement, natural aggregate or blast-furnace slag. The usual mix is one part of cement to six or eight parts of aggregate by volume. These blocks are as heavy per cubic metre as bricks, they are not good thermal insulators and their strength in resisting crushing is less than that of most well burned bricks. The colour and texture of these blocks is far from attractive and they are usually covered with plaster or a coat of rendering. These blocks are used for internal and external loadbearing walls, including walls below ground.

Lightweight aggregate concrete blocks for general use in building

The blocks are made of cement and one of the following lightweight aggregates: granulated blast-furnace slag, foamed blast-furnace slag, expanded clay or shale, or well burned furnace clinker. The usual mix is one part cement to six or eight of aggregate by volume. Of the four lightweight aggregates noted, well burned furnace clinker produces the cheapest block, which is about two-thirds the weight of a similar dense aggregate concrete block and is a considerably better thermal insulator. Blocks made from foamed blast-furnace slag are about twice the price of those made from furnace clinker, but they are only half the weight of a similar dense aggregate block and have good thermal insulating properties. The furnace clinker blocks are used extensively for walls of houses and the foamed blast-furnace slag blocks for walls of large framed buildings because of their lightness in weight.

   Lightweight aggregate concrete blocks are used primarily for internal non-loadbearing walls. These thin blocks, usually 60 or 75 mm thick, are made

with the same lightweight aggregate as those in Class 2. These blocks are more expensive than dense aggregate blocks and are used principally for non-loadbearing partitions. These blocks are manufactured as solid, hollow or cellular depending largely on the thickness of the block. The thin blocks are solid and either square edged or with a tongue and groove in the short edges so that there is a mechanical bond between blocks to improve the stability of internal partitions. The poor structural stability may be improved by the use of storey height door linings, which are secured at floor and ceiling level. Thin block internal partitions afford negligible acoustic insulation and poor support for fittings, such as bookshelves secured to them. The thicker blocks are either hollow or cellular to reduce weight and drying shrinkage.

As water dries out from precast concrete blocks, the shrinkage that occurs, particularly with lightweight blocks, may cause serious cracking of plaster and rendering applied to the surface of a wall built with them. Obviously, the wetter the blocks the more they will shrink. It is essential that these blocks be protected on building sites from saturation by rain both when they are stacked on site before use and while walls are being built.

Clay blocks

Hollow clay building blocks are made from selected brick clays that are press moulded and burnt. These hard, dense blocks are hollow to reduce shrinkage during firing and also to reduce their weight. They are grooved to provide a key for plaster, as illustrated in Figure 5.42. The standard block is 290 long × 215 mm high and 75, 100 or 150 mm thick. Clay blocks are comparatively lightweight, do not suffer moisture movement, have good resistance to damage by fire and poor thermal insulating properties. In the UK, these blocks are mainly used for non-loadbearing partitions. They are extensively used in southern Europe as infill panel walls to framed buildings where the tradition is to render the external face of buildings on which the blocks provide a substantial mechanical key for rendering and do not suffer moisture movement that would otherwise cause shrinkage cracking.
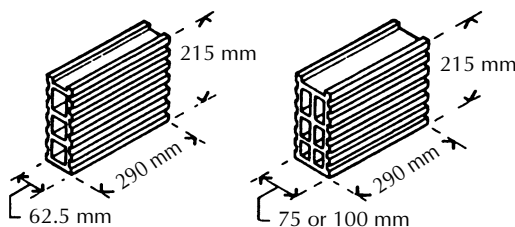
Figure 5.42　Clay blocks.

Bonding blocks

Blocks are made in various thicknesses to suit most wall requirements and are laid in stretcher bond. Thin blocks, used for non-loadbearing partitions, are laid in running stretcher bond with each block centred over and under blocks above and below. At return angles full blocks bond into the return wall in every other course, as illustrated in Figure 5.43. So as not to disturb the full width bonding of blocks at angles, for the sake of stability, a short length of cut block is used as closer and infill block. Thicker blocks are laid in off centre running bond with a three quarter length block at stop ends and sides of openings.

cut closer

thin stretcher bond

²/₃rd block

off centre running bond

running (stretcher) bond
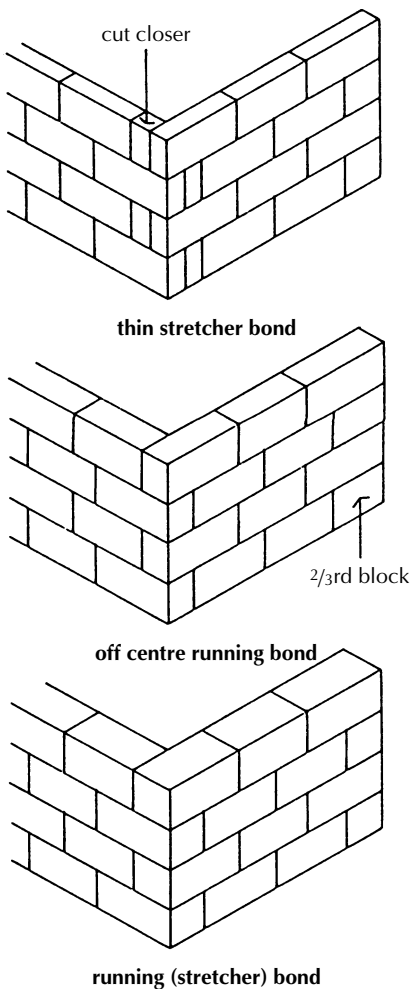
Figure 5.43   Bonding building blocks.

The off centre bond is acceptable with thicker blocks as it avoids the use of cut blocks to complete the bond at angles.

Thick blocks, whose length is twice their width, are laid in running (stretcher) bond as illustrated in Figure 5.43, and cut blocks are only necessary to complete the bond at stop ends and sides of opening. At the 'T' junctions of loadbearing concrete block walls it is sometimes considered good practice to butt the end face of the intersecting walls with a continuous vertical joint to accommodate shrinkage movements and to minimise cracking of plaster finishes. Where one intersecting wall serves as a buttress to the other, the butt joint should be reinforced by building in split end wall ties at each horizontal joint across the butt joint to bond the walls. Similarly, non-loadbearing block walls should be butt jointed at intersections and the joint reinforced with strips of expanded metal bedded in horizontal joints across the butt joint.

Concrete block walls of specially produced blocks to be used as a fairface finish are bonded at angles to return walls with specially produced quoin blocks for the sake of appearance, as illustrated in Figure 5.44. The 'L' shaped quoin blocks are made to continue the stretcher bond around the angle into the return walls. Quoin blocks are little used for other than fairface work as they are liable
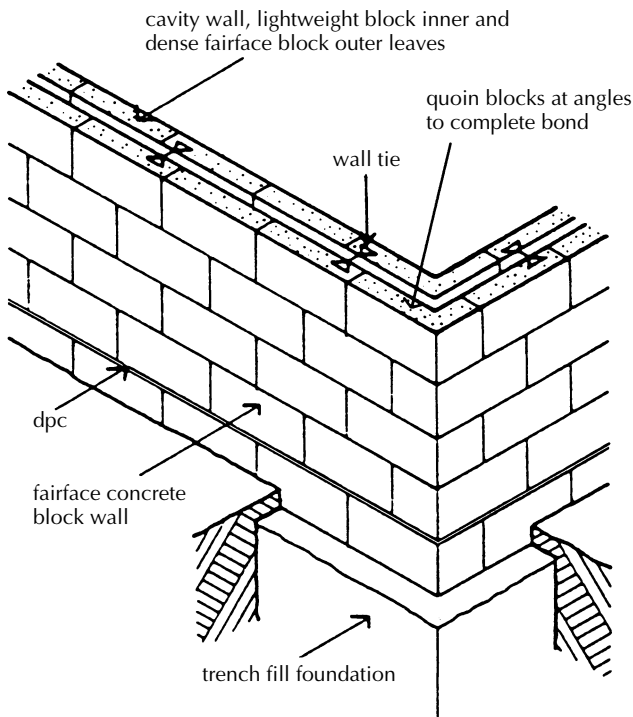
Figure 5.44   Bonding block walls.

to damage in handling and use and add considerably to the cost of materials and labour.

5.8 Mortar

It is essential that brickwork and blockwork be laid in true horizontal courses, and the only way this can be done with bricks is to lay them on mortar. The basic requirements of a mortar are that it will harden to such an extent that it can carry the weight normally carried by bricks, without crushing, and that it be sufficiently plastic when laid to take the varying sizes of bricks. It must have a porosity similar to that of the bricks and it must not deteriorate due to the weathering action of rain or frost. Sand is a natural material which is reasonably cheap and which, if mixed with water, can be made plastic, yet which has very good strength in resisting crushing. Its grains are also virtually impervious to the action of rain and frost.

Composition of mortar

The material required to bind the grains of sand together into a solid mass is termed the matrix and two materials can be used for this purpose: either lime or cement.

Aggregate for mortar – soft and sharp sand

Sand that is not washed and that contains some clay in it feels soft and smooth when held in the hand, hence the term soft sand. Sand, which is clean, feels coarse in the hand, hence the term sharp. These are terms used by bricklayers. When soft sand ('builders' sand') is used, the mortar is very smooth and plastic and it is much easier to spread and to bed the bricks in than a mortar made of sharp sand.

Matrix for mortar

The material that was used for many centuries before the advent of Portland cement as the matrix (binding agent) for mortar was lime. Lime, which mixes freely with water and sand, produces a material that is smooth, plastic and easily spread. Portland cement produces a hard dense material that has more than adequate strength for use as mortar and is largely unaffected by damp conditions. A mortar in which the advantages of lime and cement are combined is termed a 'compo' mortar.

Ready mixed mortar

Ready mixed mortars have come into use particularly on sites where extensive areas of brickwork are laid. The wet material is delivered to site, ready mixed, to save time, labour and cost of mixing on site. A wide range of lime and sand, lime cement and sand and cement and sand mixes is available. The sand may

be selected to provide a chosen colour and texture or the mix may be pigmented for the same reason. Lime mortar is delivered to site ready to use within the day of delivery. Cement mix and cement lime mortar is delivered to site ready mixed with a retarding admixture. The retarding admixture is added to cement mix mortars to delay the initial set of cement. The initial set of ordinary Portland cement occurs some 30 minutes after the cement is mixed with water, so that an initial hardening occurs to assist in stiffening the material for use as rendering on vertical surfaces, for example. The advantages of ready mixed mortar are consistency of the mix, the wide range of mixes available, saving in site labour costs and reduction of waste of material common with site mixing.

Types of mortar

Cement mortar

When fine cement powder is mixed with water a chemical action between water and cement takes place. At the completion of this reaction the nature of the cement has so changed that it binds itself very firmly to most materials. Cement is thoroughly mixed with sand and water, the reaction takes place and the excess water evaporates leaving the cement and sand to harden gradually into a solid mass. The hardening of the mortar becomes noticeable some few hours after mixing and is complete in a few days. The usual mix of cement and sand for mortar is from one part cement to three or four parts sand to one part of cement to eight parts of sand by volume, mixed with just sufficient water to render the mixture plastic. A mortar of cement and sand is very durable and is often used for brickwork below ground level and brickwork exposed to weather above roof level such as parapet walls and chimney stacks. When used with some types of bricks it can cause efflorescence. Because cement mortar has greater compressive strength than required for most ordinary brickwork and because it is not very plastic by itself it is sometimes mixed with lime and sand.

Lime mortar

Lime is manufactured by burning limestone or chalk and the result of this burning is a dirty white, lumpy material known as quicklime. When this quicklime is mixed with water a chemical change occurs during which heat is generated in the lime and water, and the lime expands to about three times its former bulk. This change is gradual and takes some days to complete, and the quicklime afterwards is said to be slaked, that is it has no more thirst for water; more precisely the lime is said to be hydrated. Lime for building is delivered to site ready slaked and is termed 'hydrated lime'. When mixed with water, lime combines chemically with carbon dioxide in the air and in undergoing this change it gradually hardens into a solid mass, which firmly binds the sand. The particular advantage of lime is that it is a cheap, reusable, readily available

Table 5.2 **Mortar mixes.**

Mortar designation	Air-entrained mixes		
	Cement:lime:sand	Masonry cement:sand	Cement:sand with plasticiser
1	1:0 to $\frac{1}{4}$:3		
2	1:$\frac{1}{2}$:4 to 4$\frac{1}{2}$	1:2$\frac{1}{2}$ to 3$\frac{1}{2}$	1:3 to 4
3	1:1:5 to 6	1:4 to 5	1:5 to 6
4	1:2:8 to 9	1:5$\frac{1}{2}$ to 6$\frac{1}{2}$	1:7 to 8
5	1:3:10 to 12	1:6$\frac{1}{2}$ to 7	1:8

Source: Taken from BS 5628:Part 3:1985 (Table 15).

material that produces a plastic material ideal for bedding bricks. Its disadvantages are that it is a messy, laborious material to mix, it gains strength slower than cement and as it is to some extent soluble in water it will lose its adhesive property in persistently damp situations. Protected from damp, a lime mortar will serve as an effective mortar for the life of most buildings.

A lime mortar is usually mixed with one part of lime to three parts of sand by volume. The mortar is plastic, easy to spread and hardens into a dense mass of good compressive strength. A lime mortar readily absorbs water and in time the effect is to reduce the adhesion of the lime to the sand and the mortar crumbles and falls out of the joints in the brickwork.

Mortar for general brickwork may be made from a mixture of cement, lime and sand in the proportions set out in Table 5.2. These mixtures combine the strength of cement with the plasticity of lime, have much the same porosity as most bricks and do not cause efflorescence on the face of the brickwork. The mixes set out in Table 5.2 are tabulated from rich mixes (1) to weak mixes (5). A rich mix of mortar is one in which there is a high proportion of matrix, that is lime or cement or both, to sand as in the 1:3 mix and a weak mix is one in which there is a low proportion of lime or cement to sand as in the mix 1:3:12. The richer the mix of mortar the greater its compressive strength and the weaker the mix the greater the ability of the mortar to accommodate moisture or temperature movements.

Proportions by volume

The general uses of the mortar mixes given in Table 5.2 are as mortar for brickwork or blockwork as follows:

❑ Mix 1 For cills, copings and retaining walls
❑ Mix 2 Parapets and chimneys
❑ Mix 3 Walls below dpc
❑ Mix 4 Walls above dpc
❑ Mix 5 Internal walls and lightweight block inner leaf of cavity

Hydraulic lime

Hydraulic lime is made by burning a mixture of chalk or limestone that contains clay. Hydraulic lime is stronger than ordinary lime and will harden in wet conditions, hence the name. Ordinary Portland cement, made from similar materials and burnt at a higher temperature, has largely replaced hydraulic lime.

Mortar plasticisers

Liquids known as mortar plasticisers, when added to water, effervesce. If very small quantities are added to mortar, when it is mixed, the millions of minute bubbles that form surround the hard sharp particles of sand and so make the mortar plastic and easy to spread. The particular application of these mortar plasticisers is that if they are used with cement mortar they increase its plasticity and there is no need to use lime. It seems that the plasticisers do not adversely affect the hardness and durability of the mortar and they are commonly and successfully used for mortars.

Jointing and pointing

Jointing

Jointing is the word used to describe the finish of the mortar joints between bricks, in brickwork that is finished fairface (not subsequently covered with plaster, rendering or other finish). Flush joints are generally made as a 'bagged' or a 'bagged in' joint. The joint is made by rubbing coarse sacking or a brush across the face of the brickwork to rub away all protruding mortar and hence leave a flush joint. This type of joint, illustrated in Figure 5.45, can most effectively be used on brickwork where the bricks are uniform in shape and comparatively smooth faced, where the mortar will not spread over the face of the brickwork.

A bucket handle joint is made by running the top face of a metal bucket handle along the joint to form a concave, slightly recessed joint, illustrated in Figure 5.45. The advantage of the bucket handle joint is that the operation compacts the mortar into the joint and improves weather resistance to some extent. A bucket handle joint may be formed by a jointing tool with or without a wheel attachment to facilitate running the tool along uniformly deep joints. Flush and bucket handle joints are mainly used for jointing as the brickwork is raised, the joint being made after the mortar has hardened sufficiently, or 'gone off'.

The struck and recessed joints shown in Figure 5.45 are more laborious to make and therefore more expensive. The struck joint is made with a pointing trowel that is run along the joint either along the edges of uniformly shaped bricks or along a wood straight edge, where the bricks are irregular in shape or coarse textured, to form the splayed back joint. The recessed joint is similarly formed with a tool shaped for the purpose. Of the joints described, the struck

flush

struck or
weathered

bucket handle
keyed
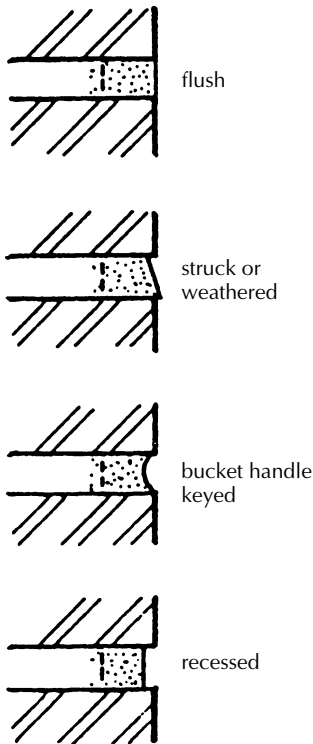
recessed

Figure 5.45   Jointing and pointing.

joint is mainly used for pointing the joints in old brickwork and the recessed joint to emphasise the profile, colour and textures of bricks for appearance sake to both new and old brickwork.

Pointing

Pointing is the operation of filling mortar joints with a mortar selected for colour and texture to either new brickwork or to old brickwork. The mortar for pointing is a special mix of lime, cement and sand or stone dust chosen to produce a particular effect of colour and texture. The overall appearance of a fairface brick wall can be altered by the selection of mortar colour and type of pointing. The joints in new brickwork are raked out about 20 mm deep when the mortar has gone off sufficiently and before it has set hard and the joints are pointed as scaffolding is removed.

The mortar joints in old brickwork that was laid in lime mortar may in time crumble and be worn away by the action of wind and rain. The joints are raked out to a depth of about 20 mm and pointed with a mortar mix of cement, lime and sand that has roughly the same density as the brickwork. The operation of raking out joints is laborious and messy and the job of filling the joints

with mortar for pointing is time consuming so that the cost of pointing old work is expensive. Pointing or re-pointing old brickwork is carried out both as protection for the old lime mortar to improve weather resistance and to improve the visual appearance of a wall.

5.9 Loadbearing brick and block walls

Functional requirements

Strength and stability

In Approved Document A there is practical guidance to meeting the requirements of the Building Regulations for the walls of small buildings of the following three types:

(1) residential buildings of not more than three storeys
(2) small single storey non-residential buildings, and
(3) small buildings forming annexes to residential buildings (including garages and outbuildings).

Height and width

The maximum height of residential buildings is given as 15 m from the lowest ground level to the highest point of any wall or roof in Approved Document A (see Figure 5.46). Height is separately defined, for example, as from the base of a gable and external wall to half the height of the gable. The height of single storey, non-residential buildings is given as 3 m from the ground to the top of the roof, which limits the guidance to very small buildings. The maximum height of an annexe is similarly given as 3 m, yet there is no definition of what is meant by annexe except that it includes garages and outbuildings. The least

Maximum height

Height should not exceed 15 m

Lowest ground level

Minimum width

Width not less than half the height
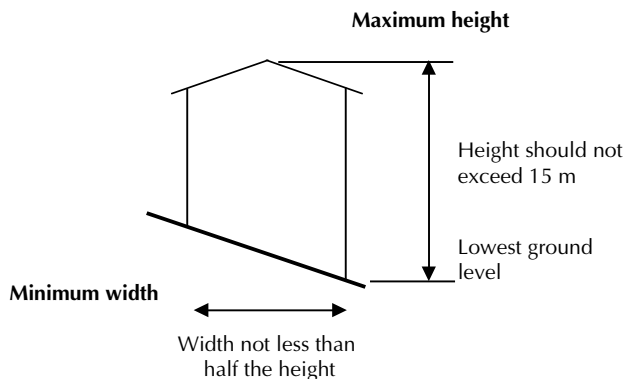
Figure 5.46   Maximum height and minimum width of walls for residential buildings (source: Approved Document A).

Where structural walls enclose
the floor area the maximum floor
area is 70 m².

Where one side of the space is not
enclosed by a wall the maximum
floor area is 30 m².
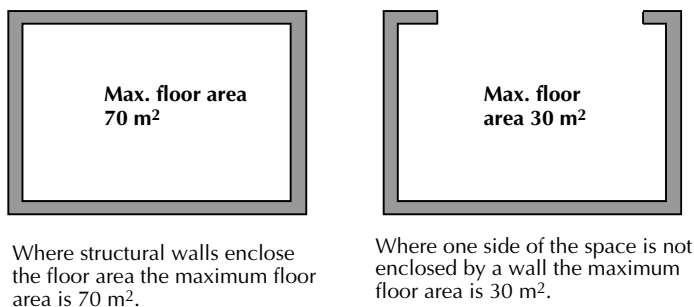
Figure 5.47   Structural walls and maximum floor area (Approved Doc A).

width of residential buildings is limited to not less than half the height. A
diagram limits the dimensions of the wing of a residential building.

One further limitation is that no floor enclosed by structural walls on all sides
should exceed 70 m² and a floor without a structural wall on one side, 30 m²
(Figure 5.47). The floor referred to is presumably a suspended floor, though it
does not say so. As the maximum allowable length of wall between buttressing
walls, piers or chimneys is given as 12 m and the maximum span for floors as
6 m, the limitation is in effect a floor some 12 × 6 m on plan. It is difficult to
understand the need for the limitation of floor area for certain 'small' buildings.

Strength
The guidance given in the Approved Document for walls of brick or block
is based on compressive strengths of 5 N/mm² for bricks and 2.8 N/mm² for
blocks for walls up to two storeys in height, where the storey height is not
more than 2.7 m and 7 N/mm² for bricks and blocks of walls of three storey
buildings where the storey height is greater than 2.7 m.

Stability
Thickness of walls
The general limitation of wall thickness given for stability is that solid walls
of brick or block should be at least as thick as one-sixteenth of the storey
height. This is a limiting slenderness ratio relating thickness of wall to height,
measured between floors and floor and roof that provides lateral support and
gives stability up the height of the wall. The minimum thickness of external,
compartment and separating walls is given in a table in Approved Document
A, relating thickness to height and length of wall as illustrated in Figure 5.48.
Compartment walls are those that are formed to limit the spread of fire and
separating walls (party walls) those that separate adjoining buildings, such as
the walls between terraced houses. Cavity walls should have leaves at least
90 mm thick and the cavity at least 50 mm wide.
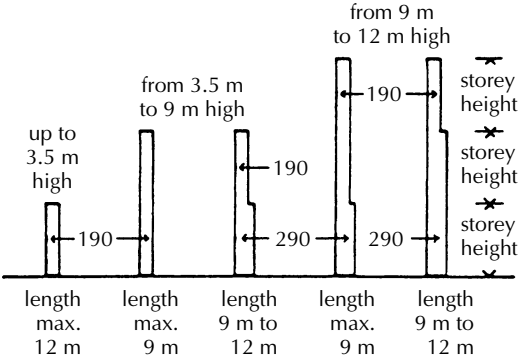
Figure 5.48   Minimum thickness of walls.

Internal loadbearing walls, except compartment and separating walls, should be half the thickness of external walls illustrated in Figure 5.48, minus 5 mm, except for the wall in the lowest storey of a three storey building which should be of the same thickness, or 140 mm, whichever is the greater.

Lateral support
For stability up the height of a wall lateral support is provided by floors and roofs as set out in Table 5.3. Walls that provide support for timber floors are given lateral support by 30×5 mm galvanised iron or stainless steel 'L' straps fixed to the side of floor joists at not more than 2 m centres for houses up to three storeys and 1.25 m centres for all storeys in all other buildings.

Lateral support from timber floors, where the joists run parallel to the wall, is provided by 30×5 mm galvanised iron on stainless steel strap anchors secured across at least three joists at not more than 2 m centres for houses up to three storeys and 1.25 m for all storeys in all other buildings. The 'L' straps

Table 5.3   Lateral support for walls.

Wall type	Wall length	Lateral support required
Solid or cavity: external compartment separating	Any length	Roof lateral support by every roof forming a junction with the supported wall
	Greater than 3 m	Floor lateral support by every floor forming a junction with the supported wall
Internal loadbearing wall (not being a compartment or separating wall)	Any length	Roof or floor lateral support at the top of each storey

Source: Taken from Approved Document A (Table 11)
The Building Regulations

Straps should be carried over at least three joists.

The nogging should be at least half the depth of the joist and at least 38 mm thick. The nogging should be packed tightly.

A   Strap fixed to the top of joists

Straps should be carried under at least three joists.

The strap can be fixed to the top or the bottom of the joists. The noggin would have to be in the lower position shown.

The nogging should be at least half the depth of the joist and at least 38 mm thick. The nogging should be packed tightly.

B   Strap fixed below timber joists

Figure 5.49   Floors providing lateral restraint to walls.

are turned down a minimum of 100 mm on the cavity side of the inner leaf of cavity walls and into solid walls. Solid timber strutting is fixed between joists under the straps as illustrated in Figure 5.49. Solid floors of concrete provide lateral support for walls where the floor bears for a minimum of 90 mm in both solid and cavity walls.

To provide lateral support to gable end walls to roofs pitched at more than 15° a system of galvanised steel straps is used. Straps 30 × 5 mm are screwed to the underside of timber noggings fixed between three rafters, as illustrated

C   Timber joist built into internal leaf of cavity

30 × 5 mm galvanised mild steel strap providing lateral support

For lateral restraint, concrete beam, must have a minimum bearing of 90 mm

D   Concrete floor built into wall
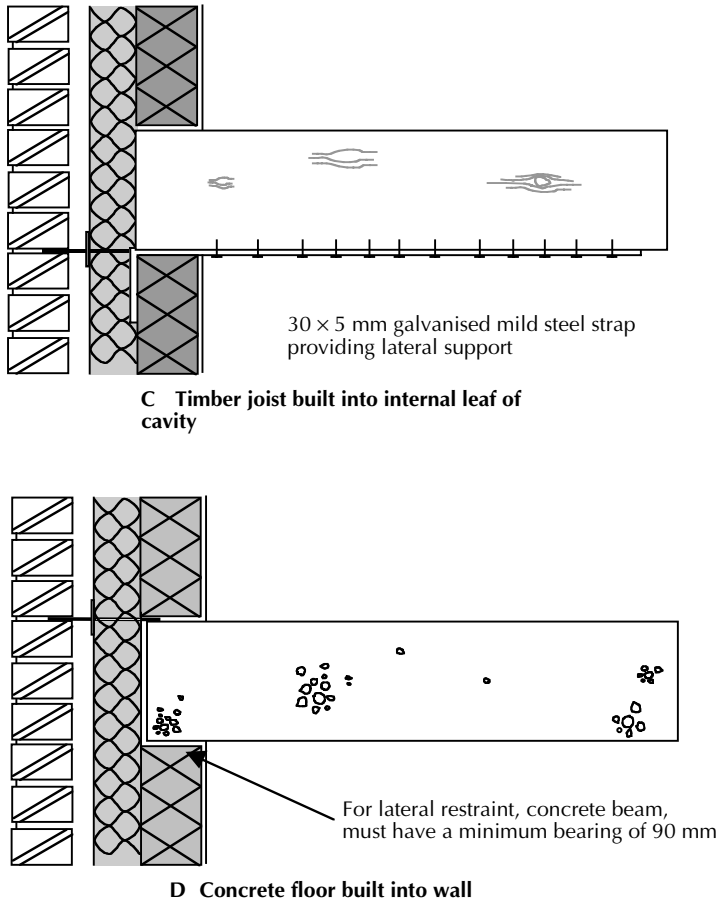
Figure 5.49   (*Continued*).

in Figure 5.50, with timber packing pieces between the rafter next to the gable and the wall. The straps should be used at a maximum of 2 m centres and turned down against the cavity face of the inner leaf of a whole building block or down into a solid wall. To provide stability along the length and at the ends of loadbearing walls there should be walls, piers or chimneys bonded to the wall at intervals of not more than 12 m, to buttress and stabilise the wall.

The maximum spacing of buttressing walls, piers and chimneys is measured from the centre line of the supports as illustrated in Figure 5.51. The maximum length between piers or buttress walls is 3 m. The minimum length of a return buttressing wall should be equal to one-sixth of the height of the supported wall. To be effective as buttresses to walls the return walls, piers and chimneys must be solidly bonded to the supported wall.

30 × 5 mm galvanised steel straps screwed to underside of timber noggins at max 2 metre centres

packing

end of strap turned down over whole block
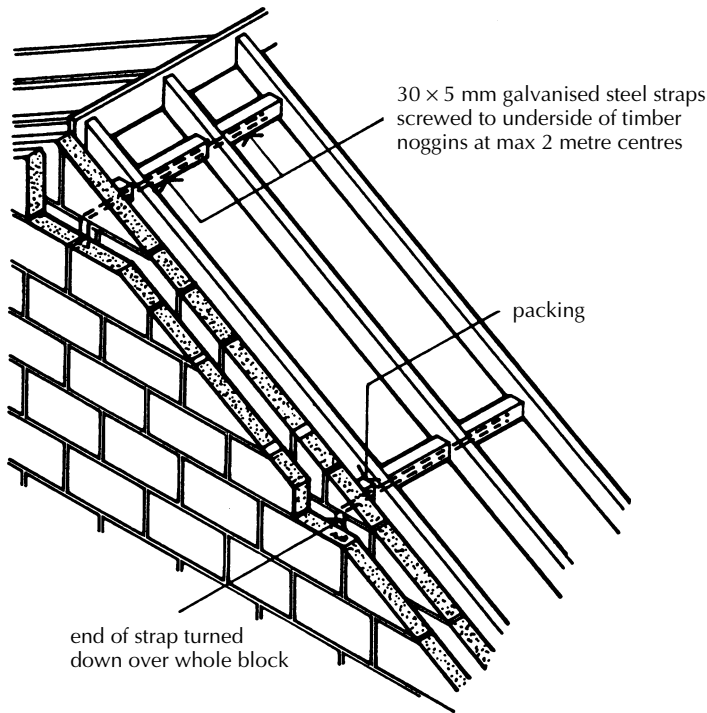
Figure 5.50   Lateral support to gable ends.

length

length

min 2T

min 2T

chimney breast

min 190 mm

lengths are measured from centre of chimney, pier and wall

return buttressing wall min length equal to $1/6$th height of supported wall
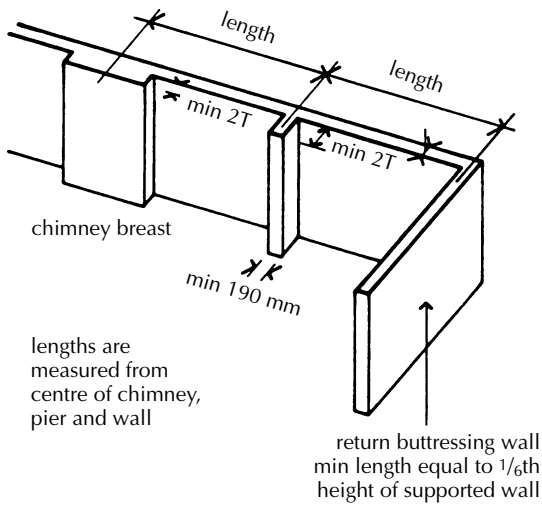
Figure 5.51   Length of walls.

Chases in walls (cuts and rebates in walls)
To limit the effect of chases cut into walls in reducing strength or stability, vertical chases should not be deeper than one-third of the thickness of solid walls or a leaf of a cavity wall and horizontal chases not deeper than one-sixteenth. A chase is a recess, cut or built in a wall, inside which small service pipes are run and then covered with plaster or walling.

5.10 Solid wall construction

Up to the early part of the twentieth century, walls were generally built as solid brickwork of adequate thickness to resist the penetration of rain to the inside face and to safely support the loads common to buildings both large and small. This has largely been replaced by cavity wall construction.

Resistance to weather

A solid wall of brick will resist the penetration of rain to its inside face by absorbing rainwater that subsequently, in dry periods, evaporates to outside air. The penetration of rainwater into the thickness of a solid wall depends on the exposure of the wall to driving rain and the permeability of the bricks and mortar to water.

A solid 1B thick wall may well be sufficiently thick to prevent the penetration of rainwater to its inside face in the sheltered positions common to urban settlements on low lying land. In positions of moderate exposure a solid wall $1\frac{1}{2}$B thick will be effective in resisting the penetration of rainwater to its inside face. In exposed positions such as high ground and near the coast, a wall 2B thick may be needed to resist penetration to inside faces, although a less thick wall protected with rendering or slate or tile hanging may be a more economical solution.

Rendering
The word rendering is used in the sense of rendering the coarse texture of a brick or block wall smooth by the application of a wet mix of lime, cement and sand over the face of the wall, to alter the appearance of the wall or improve its resistance to rain penetration, or both. The rendering dries and hardens to a decorative protective coating that varies from dense and smooth to a coarse and open texture. The materials and application of the various renders are described in Chapter 10.

Slate and tile hanging
In positions of very severe exposure to wind driven rain, as on high open ground facing the prevailing wind and on the coast facing open sea, it is necessary to protect both solid and cavity walls with an external cladding. The
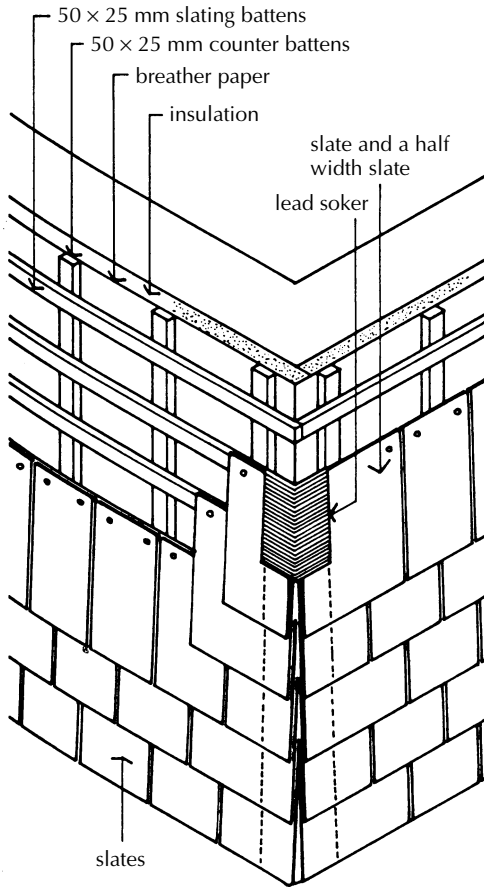
Figure 5.52   Slate hanging.

traditional wall cladding is slate or tile hanging in the form of slates or tiles hung double lap on timber battens nailed to counter battens. Slate hanging has generally been used in the north and tile in the south of Great Britain. Either natural or manufactured slates and tiles can be used. As a fixing for slating or tiling battens, 50 × 25 mm timber counter battens are nailed at 300 mm centres up the face of the wall to which timber slating or tiling battens are nailed at centres suited to the gauge (centres) necessary for double lap slates or tiles, as illustrated in Figure 5.52. As protection against decay, pressure impregnated softwood timber battens should be used and secured with non-ferrous fixings to avoid the deterioration and failure of steel fixings by rusting.

Where slate or tile hanging is used as cladding to a solid wall of buildings that are normally heated, then the thermal insulation can be fixed to the wall behind the counter battens. Rigid insulation boards are fixed with a mechanically

operated hammer gun that drives nails through both the counter battens, a breather paper and the insulation boards into the wall. The continuous layer of breather paper that is fixed between the counter battens and the insulation is resistant to the penetration of water in liquid form but will allow water vapour to pass through it. Its purpose is to protect the outer surface of the insulation from cold air and any rain that might penetrate the hanging and to allow movement of vapour from within the structure to the external environment.

For vertically hung slating it is usual to use one of the smaller slates such as 405×205 mm slate which is headnailed to 50×25 mm battens and is less likely to be lifted and dislodged in high wind than longer slates would be. Each slate is nailed with non-ferrous nails to overlap two slates below, as illustrated in Figure 5.52, and double lapped by overlapping the head of slates two courses below.

At angles and the sides of openings a slate one and a half the width of slates is used to complete the overlap. This width of slate is specifically used to avoid the use of a half width slate that might easily be displaced in wind. Internal and external angles are weathered by lead soakers, which are hung over the head of slates, to overlap and make the joint weathertight. Slate hanging is fixed either to overlap or butt to the side of window and door frames with exposed edges of slates pointed with cement mortar or weathered with lead flashings. At lower edges of slate hanging a projection is formed on or in the wall face by means of blocks, battens or brick corbel courses on to which the lower courses of slates and tiles bell outwards slightly to throw water clear of the wall below.

Tile hanging is hung and nailed to 40×20 mm tiling battens fixed at centres to counter battens to suit the gauge of plain tiles. Each tile is hung to battens and also nailed, as security against wind, as illustrated in Figure 5.53. At internal and external angles special angle tiles may be used to continue the bond around the corner, as illustrated in Figure 5.53. As an alternative and also at the sides of openings, tile and a half width tiles may be used with lead soakers to angles and pointing to exposed edges or weathering to the sides of the openings.

Openings in solid walls

For the strength and stability of walling the size of openings in walls is limited by regulations.

Jambs of openings

The jambs of openings for windows and doors in solid walls may be plain (square) or rebated. Plain or square jambs are used for small section window or door frames of steel and also for larger section frames where the whole of the external face of frames is to be exposed externally. The bonding of brickwork at square jambs is the same as for stop ends and angles with a closer next to a header in alternate courses to complete the bond.
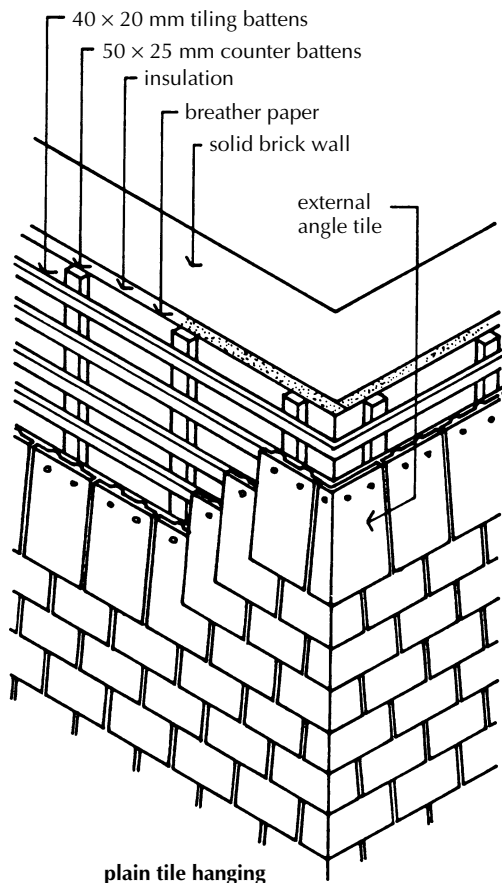
plain tile hanging

Figure 5.53   Tile hanging.

Rebated jambs

Window and door frames made of soft wood have to be painted for protection from rain, for if wood becomes saturated it swells and in time may decay. With some styles of architecture it is thought best to hide as much of the window frame as possible. So either as a partial protection against rain or for appearance sake, or for both reasons, the jambs of openings are rebated. Figure 5.54 is a diagram of one rebated jamb and terms commonly used. The thickness of brickwork that shows at the jamb of openings is described as the reveal. With rebated jambs there is an inner reveal and an outer reveal separated by the rebate.

Bonding of bricks at rebated jambs

In order to close the gaps left by bonding at the jamb specially cut bricks are used. There is a $\frac{1}{4}$B overlap caused by bonding, so at jambs special closer
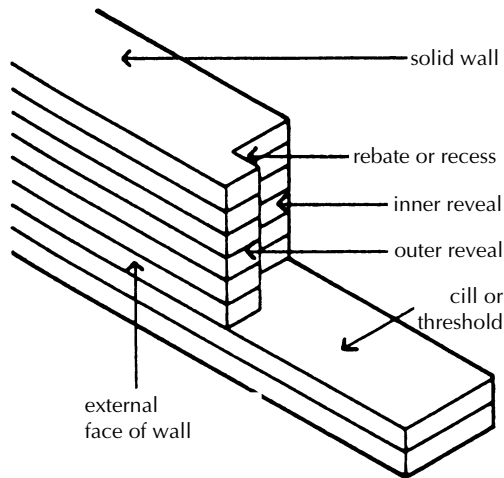
Figure 5.54   Rebated jamb.

bricks $\frac{1}{4}$B wide have to be used. Provided that the outer reveal is $\frac{1}{2}$B wide, the following basic rules will apply irrespective of the sort of bond used or the thickness of the wall. If the rebate is $\frac{1}{4}$B deep the bonding at one jamb will be arranged as illustrated in Figure 5.55. In every other course of bricks a header
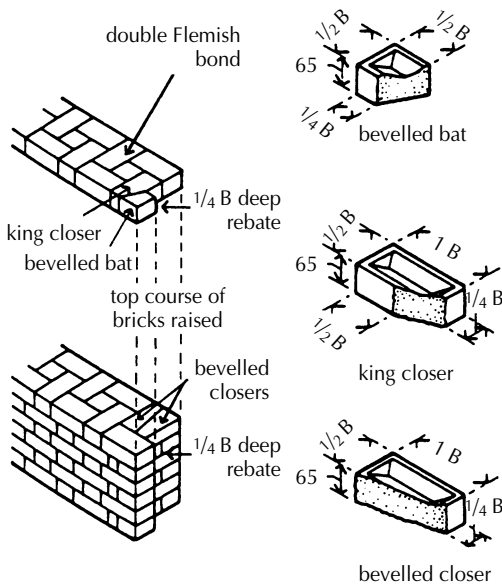
Figure 5.55   Bonding at rebated jambs.

face and then a closer of $\frac{1}{4}$B wide face must appear at the jamb or angle of the opening. To do this and at the same time to form the $\frac{1}{4}$B deep rebate and to avoid vertical joints continuously up the wall, two cut bricks have to be used.

These are a bevelled bat (a 'bat' is any cut part of a brick), which is shaped as shown in Figure 5.55, and a king closer, which is also illustrated. In the course above and below, two other cut bricks, called bevelled closers, should be used behind the stretcher brick. These two bricks are used so as to avoid a vertical joint. Figure 5.55 shows a view of a bevelled closer.

Where the rebate is $\frac{1}{2}$B deep the bonding is less complicated. An arrangement of half bats as quoin header and two bevelled closers in alternate courses for English bond and half bats and king closers in alternate courses for Flemish bond is used.

Head of openings in solid walls

Solid brickwork over the head of openings has to be supported by either a lintel or an arch. The brickwork which the lintel or arch has to support is an isosceles triangle with 60° angles, formed by the bonding of bricks, as illustrated in Figure 5.56. The vertical joints between bricks, which overlap $\frac{1}{4}$B, form the triangle. In a bonded wall if the solid brickwork inside the triangle were taken out the load of the wall above the triangle would be transferred to the bricks of each side of the opening in what is termed 'the arching effect'.

Lintel (alternatively spelt lintol) is the name given to any single solid length of timber, stone, steel or concrete built in over an opening to support the wall above it, as shown in Figure 5.56. The ends of the lintel must be built into the brick or blockwork over the jambs to convey the weight carried by the lintel to the jambs. The area of wall on which the end of a lintel bears is termed its bearing at ends. The wider the opening, the more weight the lintel has to support and the greater its bearing at ends must be to transmit the load it carries to an area capable of supporting it. For convenience its depth is usually made a multiple of brick course height, that is about 75 mm, and the lintels are not usually less than 150 mm deep.
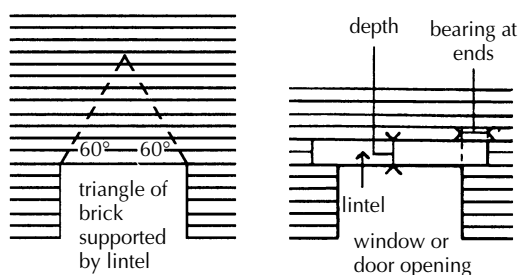
Figure 5.56   Head of openings.

Figure 5.57 Ends of reinforcing rods.

Timber lintels

Up to the early part of the twentieth century it was common practice to support the brickwork over openings on a hardwood timber lintel. Owing to advances in steel and concrete technologies, the use of timber sections as lintels in masonry construction is not common today.

Concrete lintels

Concrete is made from reasonably cheap materials, it can easily be moulded or cast when wet and when it hardens it has very good strength in resisting crushing. The one quality that concrete lacks, if it is to be used as a lintel, is tensile strength, that is strength to resist being pulled apart. To provide the necessary tensile strength, steel reinforcement is cast into the concrete. Lengths of steel rod are cast into the bottom of concrete lintels to give them strength in resisting tensile or stretching forces with a minimum cover of concrete of 15 mm to avoid the possibility of corrosion and damage to the concrete around them. Reinforcing rods are usually of round section mild steel 10 or 12 mm diameter for lintels up to 1.8 m span. The ends of the rods should be bent up at 90° or hooked as illustrated in Figure 5.57. The purpose of bending up the ends is to ensure that when the lintel does bend, the rods do not lose their adhesion to the concrete around them. After being bent or hooked at the ends, the rods should be some 50 or 75 mm shorter than the lintel at each end.

Casting lintels

The word 'precast' indicates that a concrete lintel has been cast inside a mould, and has been allowed time to set and harden before it is built into the wall. The words 'insitu-cast' indicate that a lintel is cast in position inside a timber mould fixed over the opening in walls. Precast lintels may be used for standard door and window openings, the advantage being that immediately the lintel is placed in position over the opening, brickwork can be raised on it, whereas the concrete in an insitu-cast lintel requires a timber mould or formwork and must be allowed to harden before brickwork can be raised on it. Lintels are cast insitu if a precast lintel would have been too heavy or cumbersome to have been hoisted and bedded in position. Precast lintels must be clearly marked to make certain that they are bedded with the steel reinforcement in its correct place, at the bottom of the lintel. Usually the letter 'T' or the word 'Top' is cut into the top of the concrete lintel while it is still wet.

Prestressed concrete lintels

A prestressed lintel is made by casting concrete around high tensile, stretched wires, which are anchored to the concrete so that the concrete is compressed by the stress in the wires (see also Volume 2). The load applied by the stressed wires, which compress the concrete, has to be overcome before the lintel will bend. Two types of prestressed concrete lintel are made: composite lintels and non-composite lintels.

Composite lintels are stressed by wires at the centre of their depth and are used with brickwork, which acts as a composite part of the lintel in supporting loads. These comparatively thin precast lintels are built in over openings and brickwork is built over them. Prestressed lintels over openings more than 1200 mm wide should be supported to avoid deflection, until the mortar in the brickwork has set. When used to support blockwork the composite strength of these lintels is considerably less than when used with brickwork.

Non-composite prestressed lintels are made for use where there is insufficient brickwork over to act compositely with the lintel and also where there are heavy loads. These lintels are made to suit brick and block wall thicknesses, as illustrated in Figure 5.58. They are mostly used for internal openings, the inner skin of cavity walls and the outer skin where it is covered externally.

Precast, or prestressed lintels may be used over openings in both internal and external solid walls. In external walls prestressed lintels are used where the wall is to be covered with rendering externally and for the inner leaf of cavity walls where the lintel will be covered with plaster. Precast reinforced concrete lintels may be exposed on the external face of both solid and cavity walling where the appearance of a concrete surface is acceptable or desired.
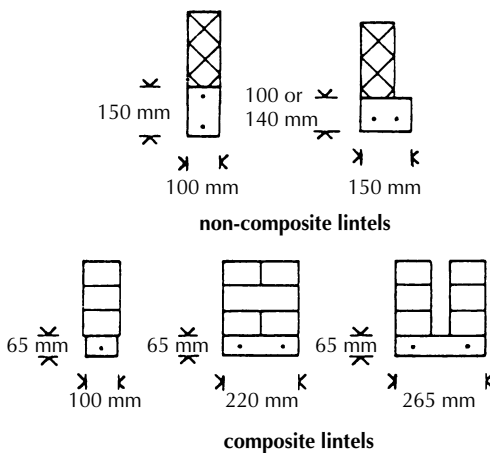
Figure 5.58   Prestressed lintels.
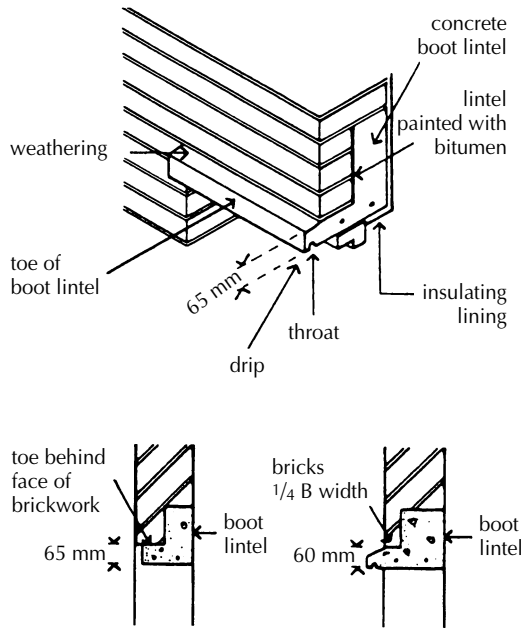
Figure 5.59   Boot lintels.

Boot lintels

The lintel is boot-shaped in section with the toe part showing externally. The toe is usually made 65 mm deep. The main body of the lintel is hidden inside the wall and it is this part of the lintel which does most of the work of supporting the brickwork (see Figure 5.59). Sometimes the detail is built so that the toe of the lintel finishes 25 or 40 mm back from the external face of the wall, as in Figure 5.59, to improve the visual appearance. The brickwork built on the toe of the lintel is usually $\frac{1}{2}$B thick for openings up to 1.8 m wide. The 65 mm deep toe, if reinforced as shown, is capable of safely carrying the two or three courses of $\frac{1}{2}$B thick brickwork over it. The brickwork above the top of the main part of the lintel bears mainly on it because the bricks are bonded. If the opening is wider than 1.8 m the main part of the lintel is sometimes made sufficiently thick to support most of the thickness of the wall over, as in Figure 5.59. The bearing at ends where the boot lintel is bedded on the brick jambs should be of the same area as for ordinary lintels.

Boot lintels should not be used in cavity wall construction because the solid concrete provides a thermal bridge across the cavity wall. Concrete lintels can be used in a cavity wall where two separate lintels are used to support each skin (Figure 5.60). The gap between the two skins of brickwork and blockwork can be filled with an insulated cavity closer.

External environment

Internal environment

dpm – Cavity tray

Head of opening Lintel

Cavity closer filled with insulating material

Reinforced concrete lintel

Reconstructed stone lintel ('art stone' lintel) or concrete lintel with stone face.

By using two separate concrete lintels the heat does not flow readily across the cavity.

Cill

Section of window head and cill
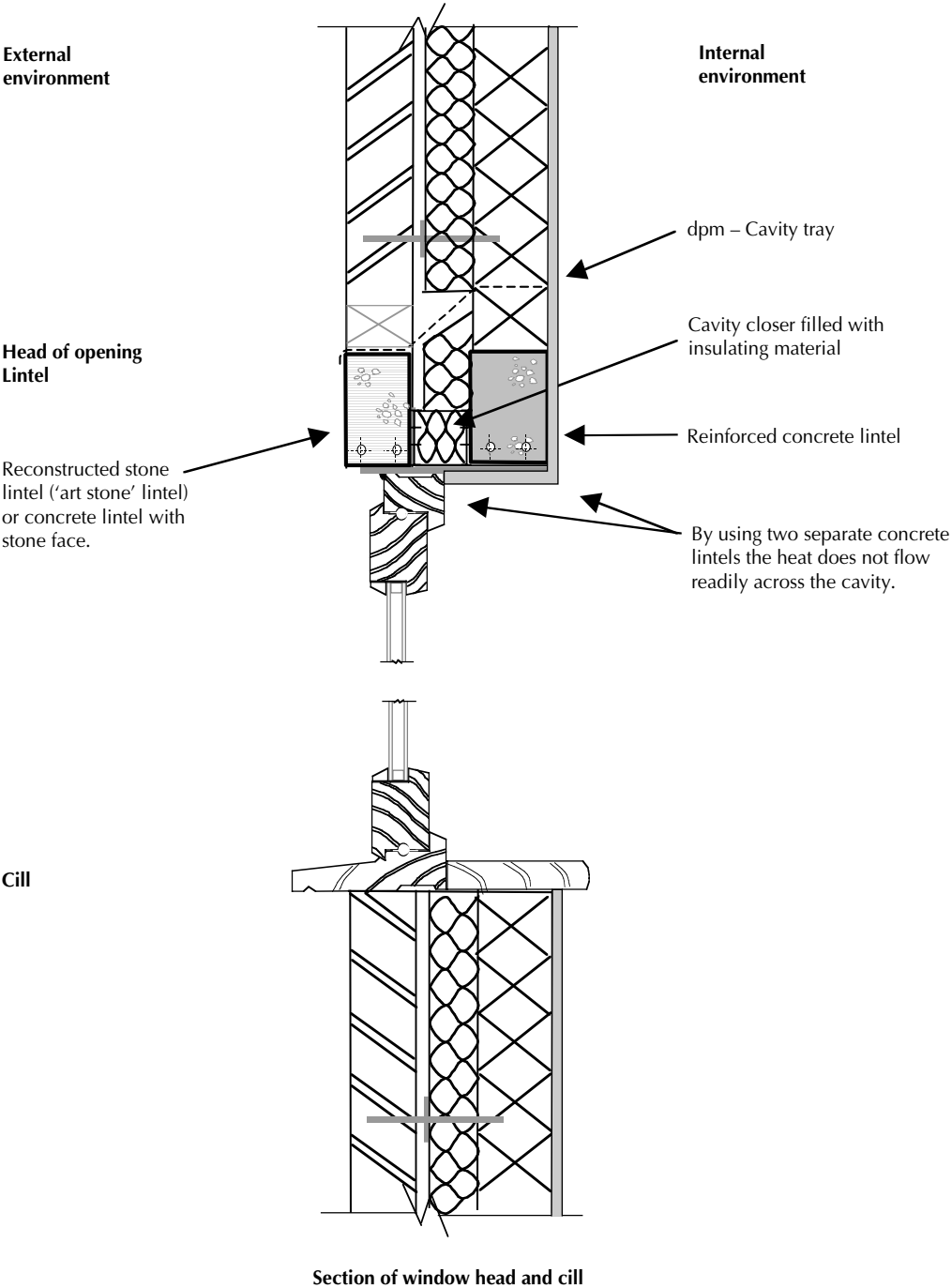
Figure 5.60   Seprate concrete lintels to avoid thermal bridge (cavity wall).
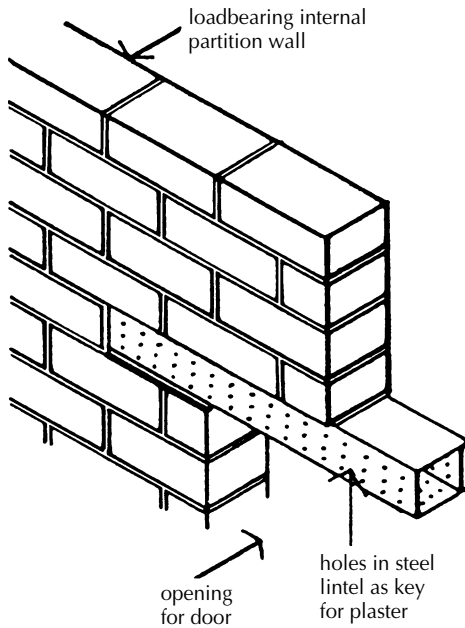
Figure 5.61   **Steel lintels in internal walls.**

Pressed steel lintels

Galvanised pressed steel lintels may be used as an alternative to concrete as a means of support to both loadbearing and non-loadbearing internal walls. Mild steel strip is pressed to shape, welded as necessary and galvanised. The steel lintels for support over door openings in loadbearing internal walls are usually in hollow box form, as illustrated in Figure 5.61. A range of lengths and sections is made to suit standard openings, wall thicknesses, course height for brickwork and adequate bearing at ends. For use over openings in loadbearing concrete block internal walls, it is usually necessary to cut blocks around the bearing ends of these shallow depth lintels.

The exposed lintel faces are perforated to provide a key for plaster. To support thin, non-loadbearing concrete blocks over narrow door openings in partition walls, a small range of corrugated, pressed steel lintels is made to suit block thickness. These shallow depth, galvanised lintels are made to match the depth of horizontal mortar joints to avoid cutting of blocks. The corrugations provide adequate key for plaster run over the face of partitions and across the soffit of openings, as illustrated in Figure 5.62. These lintels act compositely with the blocks they support. To prevent sagging they should be given temporary support at mid-span until the blocks above have been laid and the mortar hardened. Photograph 5.2 refers.

The top of the lintel is shaped so that any water which enters the cavity is shed to the external leaf.

Perforations in the steel help improve the bond and slightly reduce the heat flow across the lintel
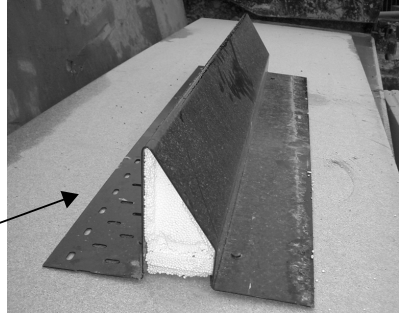
A   Pressed steel lintel with insulation

B   Lintel placed on cavity wall ready to receive brickwork

Steel lintel

Insulation

Cavity closer

Plaster board – ribbon of plaster will be used to seal the gap between the blockwork and plaster board.

C   Underside of lintel can be seen, plaster board will be used to cover the exposed lintel

Photograph 5.2   Pressed steel lintels (cavity walls).
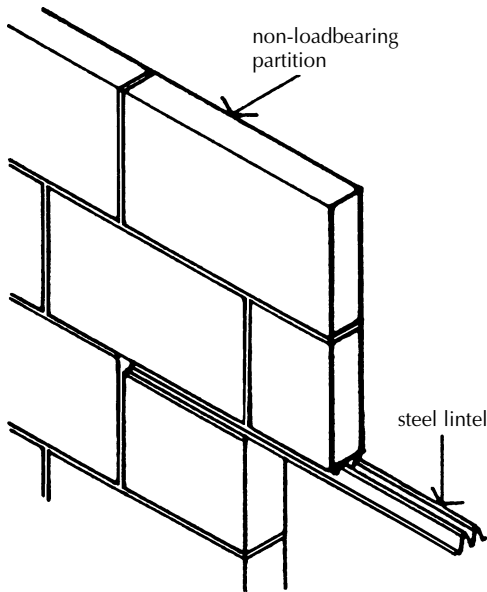
Figure 5.62   Corrugated steel lintel in internal wall.

Thermal bridging through lintels

Where there is a continuous mass of material across a cavity the heat flow through that material is likely to be considerable. Even with pressed steel lintels, which incorporate insulation (Figure 5.63), there is likely to be a continuous piece of steel that links the internal and external environment. Figure 5.64 illustrates how heat energy finds its way across the cavity. The use of two separate concrete lintels is more effective at reducing the heat flow and thermal (cold) bridging.

Brick lintels

A brick lintel may be formed as bricks on end, bricks on edge or coursed bricks laid horizontally over openings. The small units of brick, laid in mortar, give poor support to the wall above and usually need some form of additional support. A brick on-end lintel is generally known as a 'soldier arch' or 'brick on end' arch. The word arch here is wrongly used as the bricks are not arranged in the form of an arch or curve but laid flat. The brick lintel is built with bricks laid on end with stretcher faces showing, as illustrated in Figure 5.65. For openings up to about 900 mm wide it was common to provide some support for soldier arches by building the lintel on the head of timber window and door frames. The wood frame served as temporary support as the bricks were laid, and support against sagging once the wall was built.

A variation was to form skew back bricks at each end of the lintel with cut bricks so that the slanting surface bears on a skew brick in the jambs, as

External environment

Internal environment

dpm – cavity tray (not always necessary with pressed steel lintels)

Head of opening Lintel

Pressed steel lintel filled with insulation

Weep hole

Section of window head
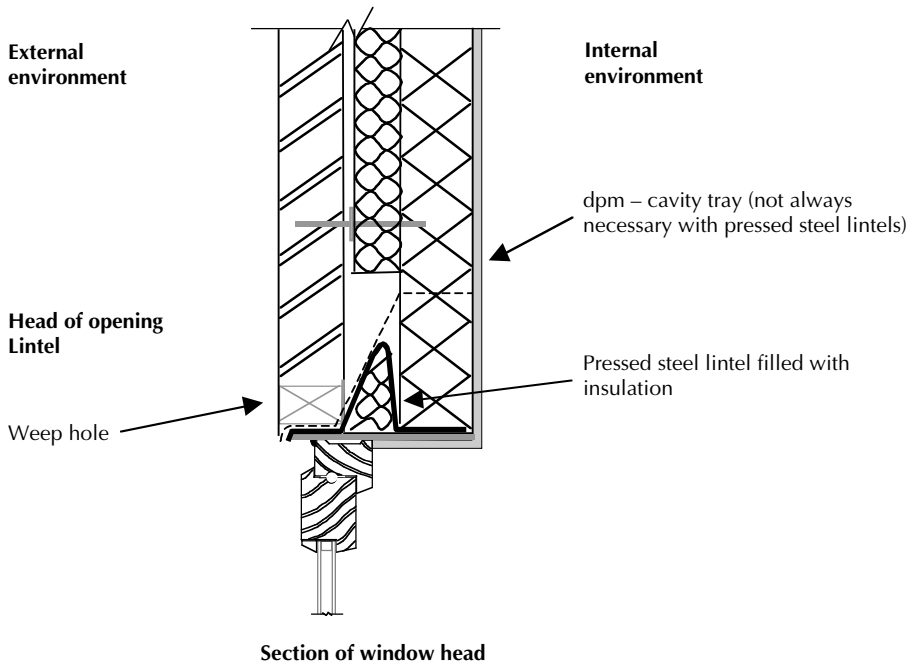
Figure 5.63   Section of pressed steel lintel.

illustrated in Figure 5.65. The skew back does give some little extra stability against sagging. For openings more than 900 mm wide a brick on end lintel may be supported by a 50 × 6 mm iron bearing bar, the ends of which are built into jambs as illustrated in Figure 5.66A. The bearing bar provides little effective support and may in time rust. As a more effective alternative a steel 50 or 75 mm angle is built into jambs to give support to the lintel. The 50 mm flange of the angle supports the back edge of the bricks and may be masked by the window or door frame.

Another method of support was to drill a hole in each brick of the lintel. This can only successfully be done with fine grained bricks such as marls or gaults. Through the holes in the bricks a round-section mild steel rod is threaded and the ends of the rod are built into the brickwork each side of the lintel. This method of supporting the lintel is quite satisfactory but is somewhat expensive because of the labour involved.

A more satisfactory method of providing support for brick on edge lintels is by wall ties cast into a concrete lintel. The lintel bricks are laid on a temporary supporting soffit board. As the bricks are laid, wall ties are bedded between joints. An insitu reinforced concrete lintel is then cast behind the brick lintel so that when the concrete has set and hardened the ties give support, as illustrated in Figure 5.66B.

Pressed steel lintel: white area of thermal image
shows transfer of heat (cold bridge) through lintel.
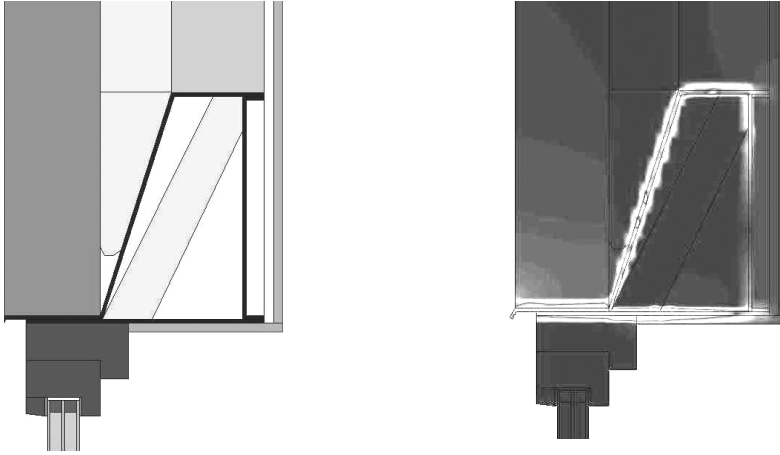
A   Section through window head with a single pressed steel lintel

With two separate lintels the transfer of heat (white area) does
not flow through the lintel across the cavity. However, the
window and window frame still allow heat to flow.

B   Section through window with two separate lintels

**Figure 5.64   Thermal bridging: single lintel and separate lintels (Thermal images
courtesy of David Roberts).**

Brick arches

An arch, which is an elegant and structurally efficient method of supporting
brickwork, has for centuries been the preferred means of support for brickwork
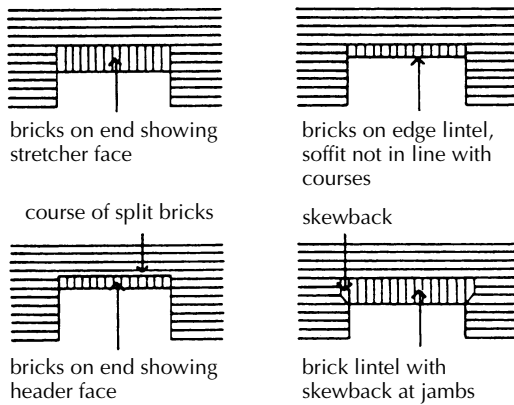
Figure 5.65   Brick lintels.

over the small openings for doors and windows and for arcades, viaducts and bridges.

Semi-circular arch

The most efficient method of supporting brickwork over an opening is by the use of a semi-circular arch, which transfers the load of the wall it supports most directly to the sides of the opening through the arch, Figure 5.67. A segmented arch, which takes the form of a segment (part) of a circle, is less efficient in that it transmits loads to the jambs by both vertical and outward thrust.

Rough and axed arches

The two ways of constructing a curved brick arch are with bricks laid with wedge shaped mortar joints or with wedge-shaped bricks with mortar joints of uniform thickness, as illustrated in Figure 5.68. An arch formed with uncut

(A) Bearing bar   **(B) Wall ties**
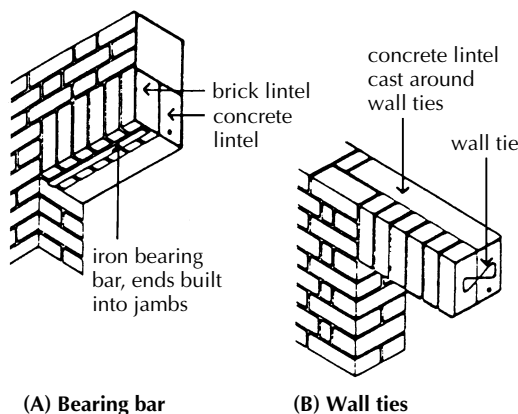
Figure 5.66   (A) Bearing bar for lintel. (B) Wall tie support for lintel.
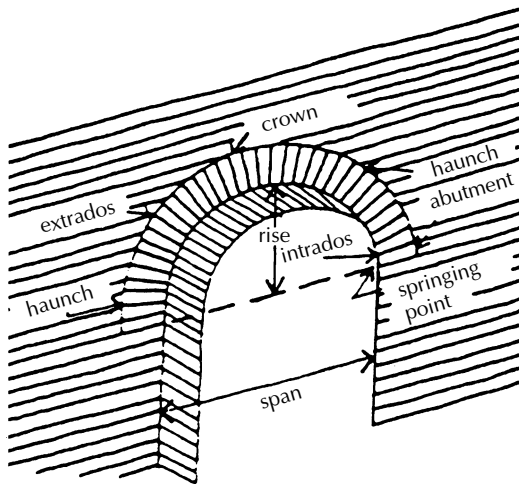
Figure 5.67   Semi-circular brick arch.

bricks and wedge shaped mortar joints is termed a rough brick arch because the mortar joints are irregular and the finished effect is rough. In time the joints, which may be quite thick at the crown of the arch, may tend to crack and emphasise the rough appearance. Rough archwork is not generally used for fairface work.

Arches in fairface brickwork are usually built with bricks cut to wedge shape with mortar joints of uniform width. The bricks are cut to the required wedge shape by gradually chopping them to shape, hence the name 'axed bricks'. Any good facing brick, no matter how hard, can be cut to a wedge shape either on or off the building site. A template, or pattern, is cut from a sheet of zinc to the exact wedge shape to which the bricks are to be cut. The template is laid on the stretcher or header face of the brick as illustrated in Figure 5.69. Shallow cuts are made in the face of the brick each side of the template. These cuts are made with a hacksaw blade or file and are to guide the bricklayer in cutting the brick. Then, holding the brick in one hand, the bricklayer gradually chops the brick to the required wedge shape. When the brick has been cut to

uncut bricks with
wedge shaped
mortar joints

bricks cut to a
wedge shape and
mortar joints of
uniform thickness

Figure 5.68   Rough and axed arches.

zinc template   **scutch**
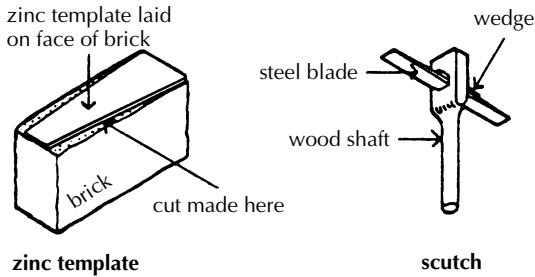
Figure 5.69   Axed brick.

a wedge shape the rough, cut surfaces are roughly levelled with a coarse rasp. From the description this appears to be a laborious operation but in fact the skilled bricklayer can axe a brick to a wedge shape in a few minutes. The axed wedged-shaped bricks are built to form the arch with uniform 10 mm mortar joints between the bricks.

Gauged bricks
Gauged bricks are those that have been accurately prepared to a wedge shape so that they can be put together to form an arch with very thin joints between them. This does not improve the strength of the brick arch and is done entirely for reasons of appearance. Hard burned clay facing bricks cannot be cut to the accurate wedge shape required for this work because the bricks are too coarse grained. One type of brick used for gauged brickwork is called a rubber brick (or brick rubbers) because its composition is such that it can be rubbed down to an accurate shape on a flat stone. Rubber bricks are made from fine grained sandy clays. The bricks are moulded and then baked to harden them, and the temperature at which these bricks are baked is lower than that at which clay bricks are burned, the aim being to avoid fusion of the material of the bricks so that they can easily be cut and accurately rubbed to shape.

Sheet zinc templates, or patterns, are cut to the exact size of the wedge-shaped brick voussoirs. These templates are placed on the stretcher or header face of the brick to be cut and the brick is sawn to a wedge shape with a brick saw. Then they are carefully rubbed down by hand on a large flat stone until they are the exact wedge shape required as indicated by the template. The gauged rubber bricks are built to form the arch with joints between the bricks as thin as 1.5 mm thick. A mortar of coarse sand and lime or cement is too coarse for narrow joints and the mortar used between the gauged bricks is composed of either fine sand and cement and lime or lime and water, depending on the thickness of joint selected. The finished effect of accurately gauged red bricks with thin white joints between them is considered very attractive. Gauged bricks are used for flat camber arches.

semi circular arches with rough voussoirs
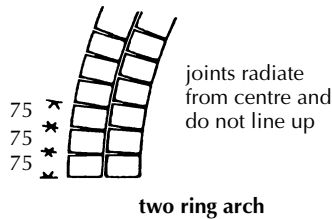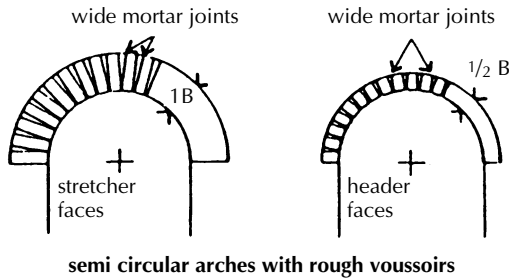
two ring arch

Figure 5.70   Two ring arch.

Two ring arch

Rough and axed bricks are used for both semi-circular and segmental arches and gauged brick for segmental and flat camber arches to avoid the more considerable cutting necessary with semi-circular arches. Rough, axed or gauged bricks can be laid so that either their stretcher or their header face is exposed. Semi-circular arches are often formed with bricks showing header faces to avoid the excessively wedge-shaped bricks or joints that occur with stretcher faces showing. This is illustrated in Figure 5.70 by the comparison of two arches of similar span first with stretcher face showing and then with header face showing. If the span of the arch is of any considerable width, say 1.8 m or more, it is often practice to build it with what is termed two or more rings of bricks, as illustrated in Figure 5.70. An advantage of two or more rings of bricks showing header faces is that the bricks bond into the thickness of the wall. Where the wall over the arch is more than 1B thick it is practical to effect more bonding of arch bricks in walls or viaducts by employing alternate snap headers (half bricks) in the face of the arch.

Segmental arch

The curve of this arch is a segment, that is part of a circle, and designers of a building can choose any segment of a circle that they think suits their design. By trial and error over many years bricklayers have worked out methods of calculating a segment of a circle related to the span of this arch, that gives a

pleasant looking shape, and that at the same time is capable of supporting the weight of brickwork over the arch. The recommended segment is such that the rise of the arch is 130 mm for every metre of span of the arch.

Centering

Temporary support for brick arches is necessary, and this is usually in the form of a timber framework to the profile of the underside of the arch. The timber support is described as centering. It is fixed and supported in the opening while the bricks of the arch are being built and the coursed brickwork over the arch laid. Once the arch and brickwork above are finished the centering is removed. A degree of both skill and labour is involved in arch building, in setting out the arch, cutting bricks for the arch and the abutment of coursed brickwork to the curved profile of the arch so that an arched opening is appreciably more expensive than a plain lintel head.

Flat camber arch

A flat camber arch is not a true arch as it is not curved and might well be more correctly named flat brick lintel with voussoirs radiating from the centre, as illustrated in Figure 5.71. The bricks from which the arch is built may be either axed or gauged to the shape required so that the joints between the bricks radiated from a common centre and the widths of voussoirs measured horizontally along the top of the arch are the same. This width will be 65 mm or slightly less, so that there are an odd number of voussoirs, the centre one being a key brick.

The centre from which the joints between the bricks radiate is usually determined either by making the skew or slating surface at the end of the arch 60° to the horizontal or by calculating the top of this skew line as lying 130 mm from the jamb for every metre of span. If the underside or soffit of this arch were made absolutely level it would appear to be sagging slightly at its centre. This is an optical illusion and it is corrected by forming a slight rise or camber on the soffit of the arch. This rise is usually calculated at 6 or 10 mm for every
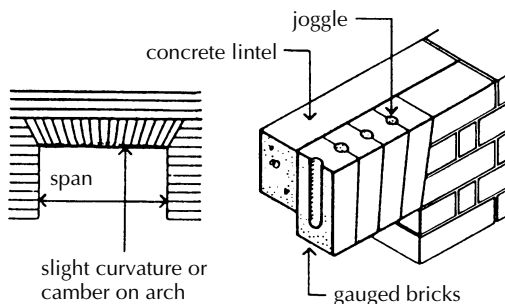
Figure 5.71   Flat gauged camber arch.

metre of span and the camber takes the form of a shallow curve. The camber is allowed for when cutting the bricks to shape. In walls built of hard coarse grained facing bricks this arch is usually built of axed bricks. In walls built of softer, fine grained facing bricks the arch is usually of gauged rubber bricks and is termed a flat gauged camber arch. This flat arch must be of such height on face that it bonds in with the brick course of the main walling. The voussoirs of this arch, particularly those at the extreme ends, are often longer overall than a normal brick and the voussoirs have to be formed with two bricks cut to shape.

Flat gauged camber arch
The bricks in this arch are jointed with lime and water, and the joints are usually 1.5 mm thick. Lime is soluble in water and does not adhere strongly to bricks as does cement. In time the jointing material, that is lime, between the bricks in this arch may perish and the bricks may slip out of position. To prevent this, joggles are formed between the bricks. These joggles take the form of semi-circular grooves cut in both bed faces of each brick, as shown in Figure 5.71, into which mortar is run.

Thermal insulation

To provide adequate insulation it is necessary to fix a layer of some lightweight insulating material to either the internal or exterior face of the wall.

Internal insulation
Internal insulation is used where solid walls have sufficient resistance to the penetration of rain, an alteration to the external appearance is not permitted or is unacceptable and the building is not occupied. A disadvantage of internal insulation is that as the insulation is at, or close to, the internal surface, it will prevent the wall behind from acting as a heat store where constant, low temperature heating is used. When insulation is applied internally there is potential for interstitial condensation to form on the face of the structural wall, therefore a vapour barrier should be used between the insulation and the blockwork or brickwork wall.

Internal insulation may be fixed to the solid brick walls of existing buildings to enhance the building's thermal insulation. It is usual to cover the insulating layer with a lining of plasterboard or plaster so that the combined thickness of the inner lining and the wall have a U value of $0.35 \, \text{W/m}^2 \, \text{K}$. Internal linings for thermal insulation are either of preformed, laminated panels that combine a wall lining of plasterboard glued to an insulation board or of separate insulation material that is fixed to the wall and then covered with plasterboard or wet plaster. The method of fixing the lining to the inside wall surface depends on the surface to which it is applied.

Adhesive fixing

Adhesive fixing directly to the inside wall face is used for preformed, laminate panels and for rigid insulation boards. Where the inside face of the wall is clean, dry, level and reasonably smooth, the panels or boards are secured with organic based gap filling adhesive, applied in dabs and strips to the back of the boards or panels or to both the boards and wall. The panels or boards are then applied and pressed into position against the wall face and their position adjusted with a foot lifter.

Where the surface of the wall is uneven or rough the panels or boards are fixed with dabs of plaster bonding, applied to both the wall surface and the back of the lining. Dabs are small areas of wet plaster bonding applied at intervals on the surface with a trowel, as a bedding and adhesive. The lining is applied and pressed into position against the wall. The wet dabs of bonding allow for irregularities in the wall surface and also serve as an adhesive. Some of the lining systems use secondary fixing in addition to adhesive. These secondary fixings are non-ferrous or plastic nails or screws driven or screwed through the insulation boards into the wall. In order to prevent air around the edges of plaster boards applied using dot and dab a ribbon (continuous strip) of plaster or fixing adhesive should be positioned around the perimeter of the plaster board. Figure 5.72 is an illustration of laminated insulation panels fixed to the inside face of a solid wall.

reduced thickness of insulation in jamb of window

laminated panels of insulation and plasterboard fixed with adhesive dabs to wall
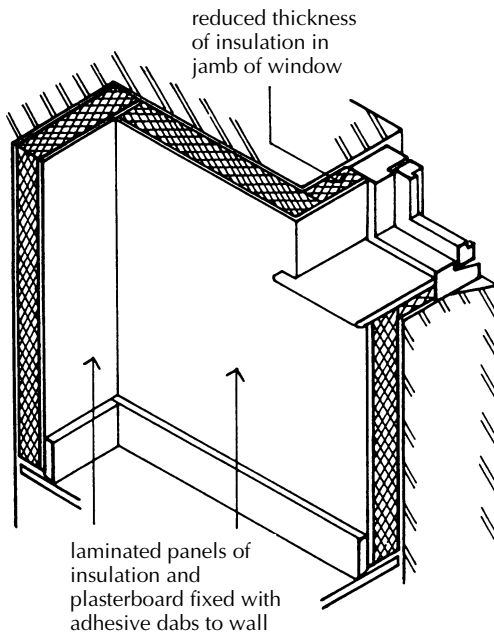
Figure 5.72   Internal insulation.

Mechanical fixing

As an alternative to adhesive fixing, the insulating lining and the wall finish can be fixed to wood battens that are nailed to the wall with packing pieces as necessary, to form a level surface. The battens should be impregnated against rot and fixed with non-ferrous fixings. The insulating lining is fixed either between the battens or across the battens and an internal lining of plasterboard is then nailed to the battens, through the insulation. The thermal resistance of wood is less than that of most insulating materials. When the insulating material is fixed between the battens there will be thermal (cold) bridges through the battens that may cause staining on wall faces.

Internal finish

An inner lining of plasterboard can be finished by taping and filling the joints or with a thin skim coat of neat plaster. A plaster finish of lightweight plaster and finishing coat is applied to the ready keyed surface of some insulating boards or to expanded metal lathing fixed to battens. Laminated panels of insulation, lined on one side with a plasterboard finish are made specifically for the insulation of internal walls. The panels are fixed with adhesive or mechanical fixings to the inside face of the wall.

Vapour check (vapour barrier)

The moisture vapour pressure from warm moist air inside insulated buildings may find its way through internal linings and condense to water on cold outer faces. Where the condensation moisture is absorbed by the insulation it will reduce the efficiency of the insulation and where condensation saturates battens, they may rot. With insulation that is permeable to moisture vapour, a vapour check should be fixed on the room side of the insulation. A vapour barrier is one that completely stops the movement of vapour through it and a vapour check is one that substantially stops vapour. As it is difficult to make a complete seal across the whole surface of a wall including all overlaps of the barrier and at angles, it is in effect impossible to form a barrier and the term vapour check should more properly be used. Sheets of polythene with edges overlapped and taped together are commonly used as a vapour check.

External insulation

Insulating materials by themselves do not provide a satisfactory external finish to walls against rain penetration, nor do they provide an attractive finish, thus they are covered with a finish of cement rendering, paint or a cladding material such as tile, slate or weatherboarding. For rendered finishes, one of the inorganic insulants, rockwool or cellular glass in the form of rigid boards, is most suited. For cladding, one of the organic insulants is used because their low U values necessitate least thickness.

Because the rendering is applied over a layer of insulation it will be subject to greater temperature fluctuations than it would be if it were applied directly to
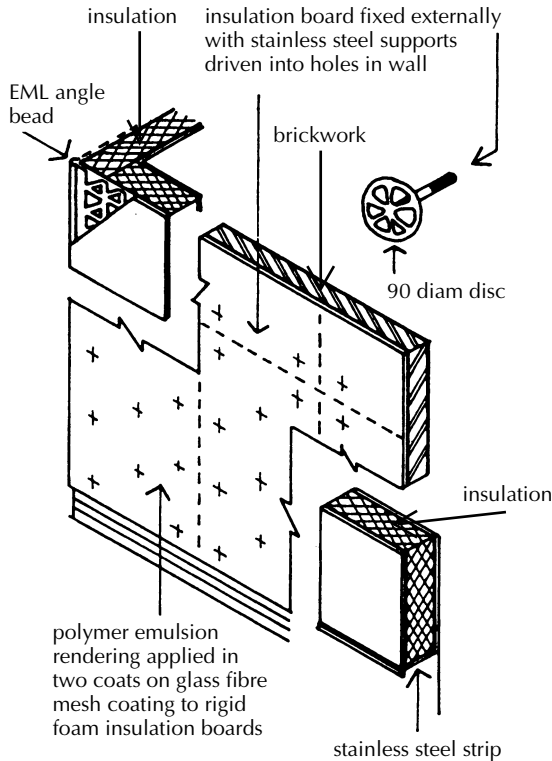
Figure 5.73   External insulation.

a wall, and so is more liable to crack. To minimise cracking due to temperature change and moisture movements, the rendering should be reinforced with a mesh securely fixed to the wall, and movement joints should be formed at not more than 6 m intervals. The use of a light coloured finish and rendering incorporating a polymer emulsion will reduce cracking. As the overall thickness of the external insulation and rendering is too great to be returned into the reveals of existing openings it is usual to return the rendering by itself, or fix some non-ferrous or plastic trim to mask the edge of the insulation and rendering. The reveals of openings will act as thermal bridges to make the inside face of the wall around openings colder than the rest of the wall. Figure 5.73 is an illustration of insulated rendering applied externally.

Tile and slate hanging, timber weatherboarding and profiled sheets can be fixed over a layer of insulating material behind the battens or sheeting rails to which these cladding materials are fixed.

Slabs of compressed mineralwool are secured to the external face of the wall with stainless steel brackets, fixed to the wall to support and restrain the blocks that are arranged with either horizontal, bonded joints or vertical and horizontal continuous joints.

5.11 Cavity wall construction

The idea of forming a vertical cavity in brick walls was first proposed early in the nineteenth century and developed through the twentieth century. The outer leaf and the cavity serve to resist the penetration of rain to the inside face and the inner leaf to support floors, provide a solid internal wall surface and, to some extent, act as insulation against transfer of heat. Various widths of cavity were proposed from the first 6 inch cavity (150 mm); a later 2 inch (50 mm) cavity followed by proposals for 3, 4 or 5 inch wide cavities. The early cavity walls were first constructed with bonding bricks laid across the cavity at intervals, to tie the two leaves together. Either whole bricks with end closers or bricks specially made to size and shape for the purpose were used. Later, iron ties were used to tie the two leaves together. From the middle of the twentieth century it became common practice to construct the external walls of houses as a cavity wall with a 50 mm wide cavity and metal wall ties until more stringent building regulations led to an increase in the cavity width to accommodate a greater depth of thermal insulating material.

Strength and stability

The practical guidance in Approved Document A accepts a cavity of 50 to 100 mm for cavity walls having leaves at least 90 mm thick, built of coursed

Partially insulated cavity

Internal skin of blockwork

Cavity ties

Insulation held against internal walls with cavity tie clips

Plastic cavity closer

External brick skin
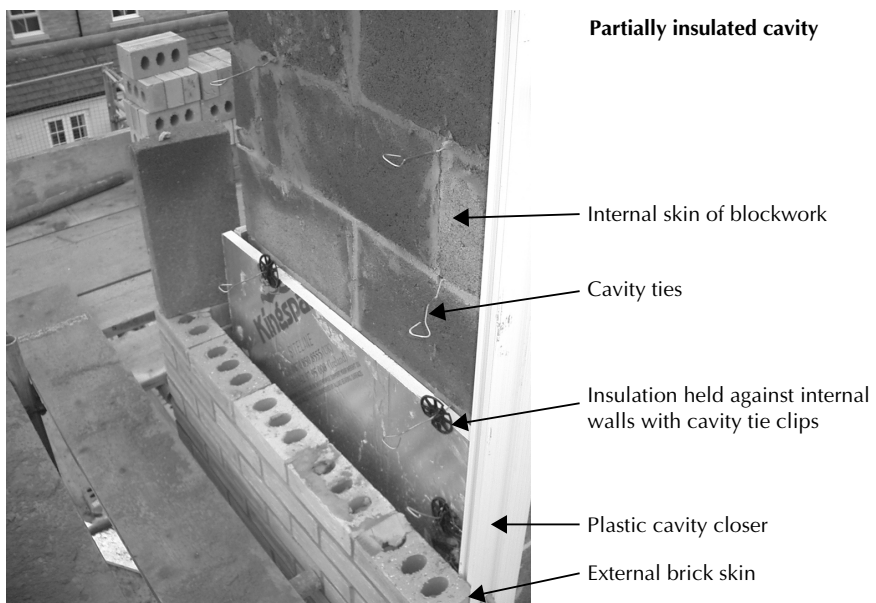
Photograph 5.3   Cavity wall construction

brickwork or blockwork with wall ties spaced at 450 mm vertically and from 900 to 750 mm horizontally for cavities of 50 to 100 mm wide, respectively. As the limiting conditions for the thickness of walls related to height and length are the same for a solid bonded wall 190 mm thick as they are for a cavity wall of two leaves each 90 mm thick, it is accepted that the wall ties give the same strength and stability to two separate leaves of brickwork as the bond in solid walls.

Wall ties

Iron ties were replaced by mild steel ties and then by mild steel ties coated with zinc to inhibit rust corrosion. The original zinc coating for ties, which was comparatively thin, has been increased in thickness in the current British Standard Specification, for improved resistance to corrosion. As added protection, the range of standard wall ties can be coated with plastic on a galvanised undercoating.

Wall ties must be protected during delivery, storage, handling and use against the inevitable knocks that may perforate the toughest coating to mild steel and the consequent probability of rust occurring. Wall ties made from stainless steel will not suffer corrosion rusting during the useful life of buildings. The sharp edges of the steel wall ties can pose a risk to the bricklayers laying the bricks. It is common practice to build up one leaf of the cavity wall to a reasonable height (one lift) with the wall ties built in. The problem that the bricklayers face is that as they build the second leaf of brick work they have to avoid the protruding sharp metal wall ties as they bend down to lay the second leaf, and a number of eye injuries have resulted. Plastic wall ties, which do not suffer from corrosion, are now much more commonly used because they do not have sharp edges and do not pose the same risk as metal ties.
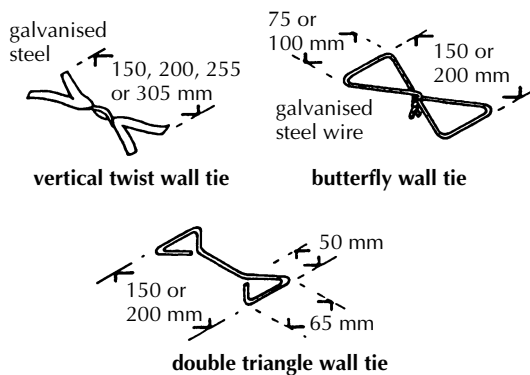
Figure 5.74   Cavity wall ties.
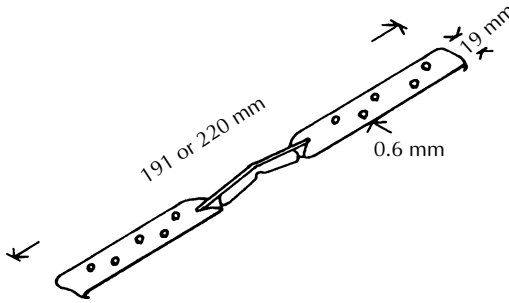
Figure 5.75   Stainless steel wall tie.

Standard section wall ties, illustrated in Figure 5.74, are the vertical twist strip, the butterfly and double triangle wire ties. As a check to moisture that may pass across the tie, the butterfly type is laid with the twisted wire ends hanging down into the cavity to act as a drip. The double triangle tie may have a bend in the middle of its length and the strip tie has a twist as a barrier to moisture passing across the tie. Of the three standard types, the butterfly is more likely to collect mortar droppings than the others.

The wall tie illustrated in Figure 5.75 is made from corrosion resistant stainless steel. The ridge at the centre of the length of the tie is designed for strength and to provide as small as possible a surface for the collection of mortar droppings. The perforations are to improve bond to mortar. The length of wall ties varies to accommodate different widths of cavity and the thickness of the leaves of cavity walls. For a 50 mm cavity with brick leaves, a 191 mm or 200 mm long tie is made. For a 100 mm cavity with brick leaves, a 220 mm long tie is used. The increased demands for higher levels of insulation has led to the development of cavity walls with 150 mm cavities; extra long wall ties with increased stiffness are now available to for such cavities.

Spacing of ties

The spacing of wall ties built across the cavity of a cavity wall is usually 900 mm horizontally and 450 mm vertically, or 2.47 ties per square metre, and staggered, as illustrated in Figure 5.76, for the conventional 50 mm wide cavity, with the spacing reduced to 300 mm around the sides of openings. In Approved Document A to the Building Regulations, the practical guidance for the spacing of ties is given as 900 and 450 mm horizontally and vertically for 50 to 75 mm cavities, 750 and 450 mm horizontally and vertically for cavities from 76 to 100 mm wide and 300 mm vertically at unbonded jambs of all openings in cavity walls within 150 mm of openings to all widths of cavities.

cavity wall, brick outer leaf, cavity,
100 mm lightweight block inner leaf

wall ties at 450 mm vertically,
900 mm horizontally and
staggered

lightweight concrete
block partition

floor
finish

dpc →

dpc

ground level →
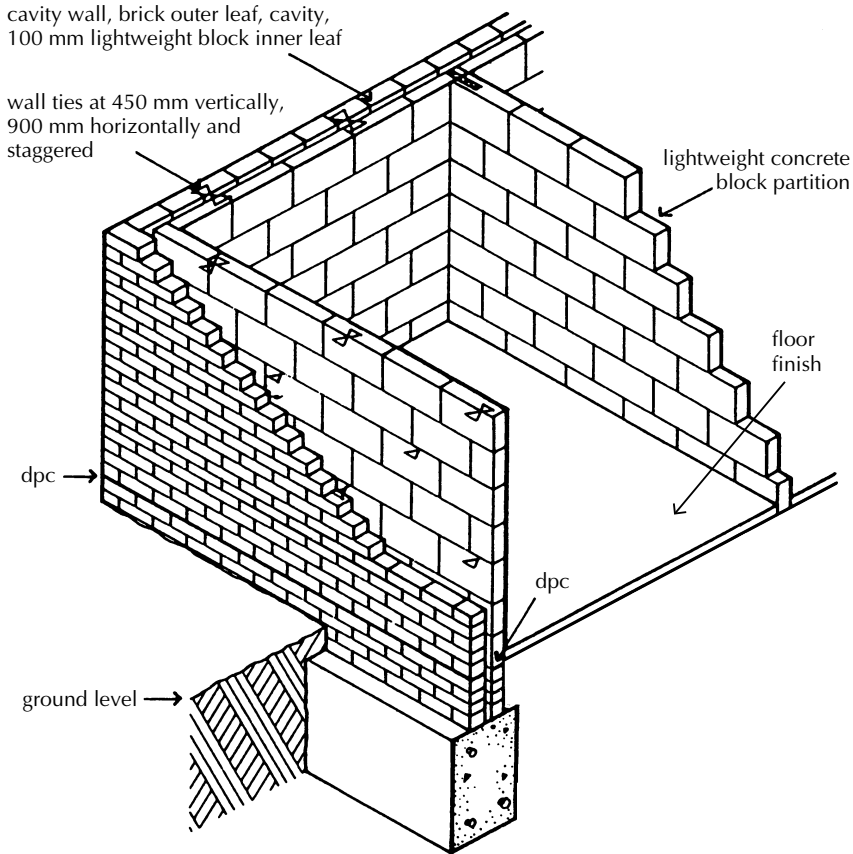
Figure 5.76   Cavity wall tie spacing.

Openings in walls

Approved Document A states that the number, size and position of openings should not impair the stability of a wall to the extent that the combined width of openings in walls between the centre line of buttressing walls or piers should not exceed two-thirds of the length of that wall together with more detailed requirements limiting the size of opening and recesses. There is a requirement that the bearing end of lintels with a clear span of 1200 mm or less may be 100 mm and above that span, 150 mm. Figure 5.77 is an illustration of a window opening in a brick wall with the terms used to describe the parts noted.

For strength and stability the brickwork in the jambs of openings has to be strengthened with more closely spaced ties and the wall over the head of the opening supported by an arch, lintels or beams. The term jamb derives from the French word *jambe*, meaning leg. From Figure 5.77, it will be seen that the brickwork on each side of the opening acts like legs, which support brickwork
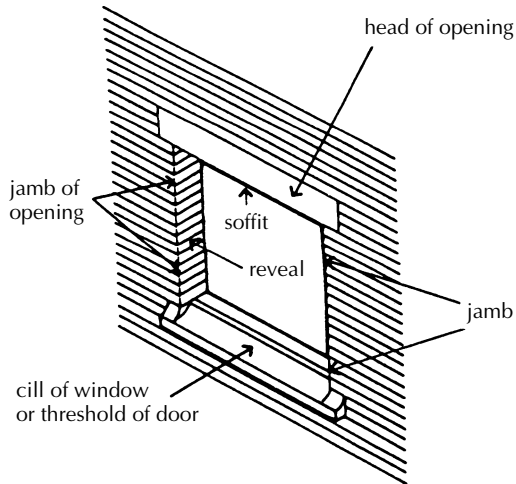
Figure 5.77   Opening in wall.

over the head of the opening. The word 'reveal' is used more definitely to describe the thickness of the wall revealed by cutting the opening and the reveal is a surface of brickwork as long as the height of the opening. The lower part of the opening is a cill (alternatively spelt sill) for windows or a threshold
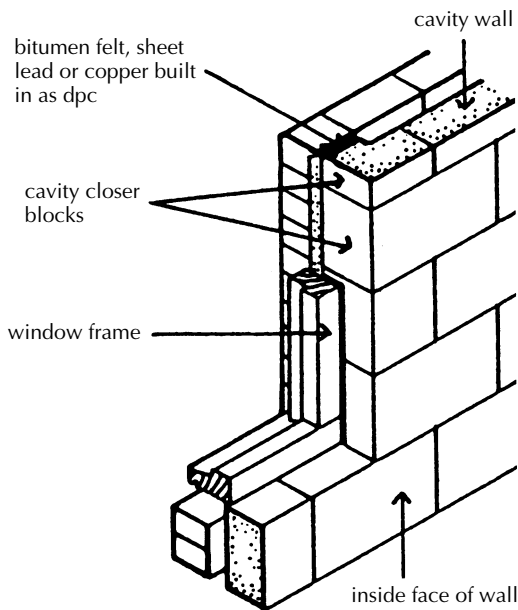
Figure 5.78   Solid closing of cavity at jambs.

Cavity closer is inserted between the two masonry skins.
The closer insulates the cavity and acts as a vertical dpc.

Photograph 5.4   Sealing the cavity in a wall opening: cavity closer

for doors. The jambs of openings may be plain or square into which the door or window frames are built or fixed or they may be rebated with a recess, behind which the door or window frame is built or fixed.

It was practice to build in cut bricks or blocks as cavity closers at the jambs of openings to maintain comparatively still air in the cavity as insulation. To prevent penetration of water through the solid closing of cavity walls at jambs, a vertical dpc was built in as illustrated in Figure 5.78. Strips of bitumen felt or lead were nailed to the back of wood frames and bedded between the solid filling and the outer leaf as shown.

It has become more common to insert plastic cavity closers, which reduce heat flow and prevent the passage of moisture across the cavity (Figure 5.79).

As an alternative to solidly filling the cavity at jambs with cavity closers, window or door frames were used to cover and seal the cavity. Pressed metal subframes to windows were specifically designed for this purpose, as illustrated in Figure 5.80. With mastic pointing between the metal subframe and the outer reveal, this is a satisfactory way of sealing cavities. With the increasing requirement for insulation it has become practice to use cavity insulation as the most practical position for a layer of lightweight material. If the cavity insulation is to be effective for the whole of the wall it must be continued up to

Typical thermal bridges

- Plastic cavity closer fixed to brickwork and nailed into mortar joints

- Insulated closer slots into rebate

- The plaster will hide the inside edge of the closer and the window or door frame will hide the external edge of the cavity closer
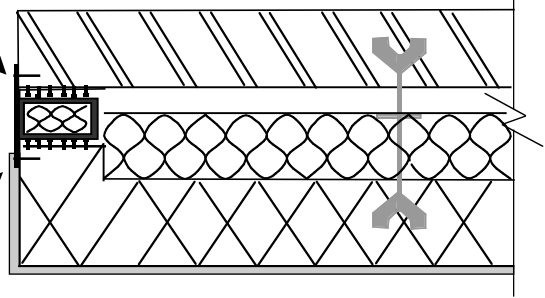
Plan: section of window jamb

Figure 5.79 **Cavity closer.**

the back of window and door frames, as a solid filling of cavity at jambs would be a less effective insulator and act as a thermal or cold bridge.

With the revision of the requirement of the Building Regulations for enhanced insulation it has become practice to use cavity insulation continued up to the frames of openings, as illustrated in Figure 5.81 and to use cavity closers, Figure 5.79, to avoid the cold bridge effect caused by solid filling. Door and window frames are set in position to overlap the outer leaf with a resilient mastic pointing as a barrier to rain penetration between the frame and the jamb. With a cavity 100 mm wide and cavity insulation as partial fill, it is necessary

insulated cavity

cavity closed by subframe

plaster

screw fixing

jamb of steel subframe

standard metal casement
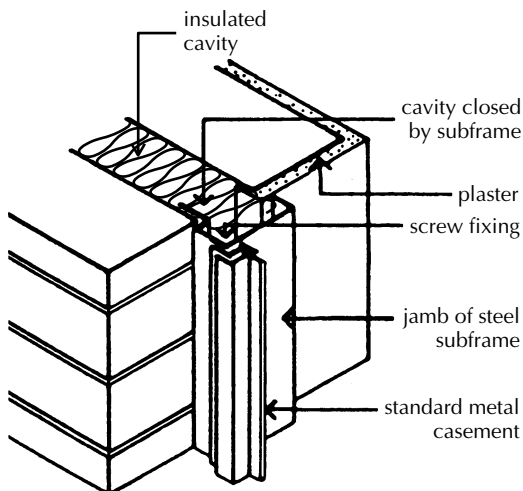
Figure 5.80 **Cavity closed with frame.**
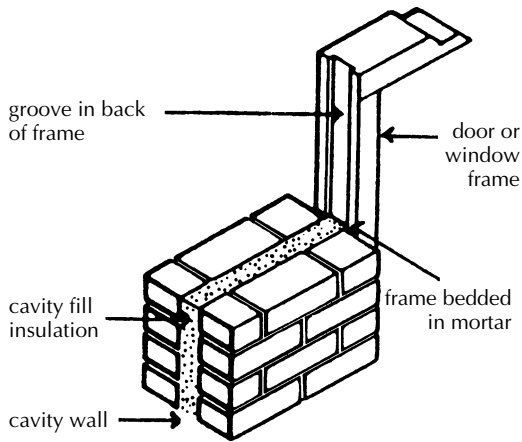
Figure 5.81   Cavity fill insulation.

to cover the part of the cavity at jambs of openings that is not covered by the frame. This can be effected by covering the cavity with plaster on metal lath or by the use of jamb linings of wood, as illustrated in Figure 5.82. With this form of construction at the jambs of openings there is no purpose in forming a vertical dpc at jambs. The advantages of the wide cavity is that the benefit of the use of the cavity insulation can be combined with the cavity air space as resistance to the penetration of water to the inside face of the wall.

Cills and thresholds of openings

A cill is the horizontal finish to the wall below the lower edge of a window opening on to which wind driven rain will run from the hard, smooth, impermeable surface of window glass. The function of a cill is to protect the wall below a window. Cills are formed below the edge of a window and shaped or formed to slope out and project beyond the external face of the wall, so that water runs off. The cill should project at least 45 mm beyond the face of the wall below and have a drip on the underside of the projection. The cavity insulation shown in Figure 5.82 is carried up behind the stone cill to avoid a cold bridge effect and a dpc is fixed behind the cill as a barrier to moisture penetration. A variety of materials may be used as a cill, such as natural stone, cast stone, concrete, tile, brick and non-ferrous metals. The choice of a particular material for a cill depends on cost, availability and, to a large extent, on appearance. As a barrier to the penetration of rain to the inside face of a cavity wall it is good practice to continue the cavity up and behind the cills.

The threshold to door openings serves as a finish to protect a wall or concrete floor slab below the door. Thresholds are commonly formed as part of a step up to external doors as part of the concrete floor slab with the top surface of the threshold sloping out. Alternatively, a natural stone or cast stone threshold may be formed.
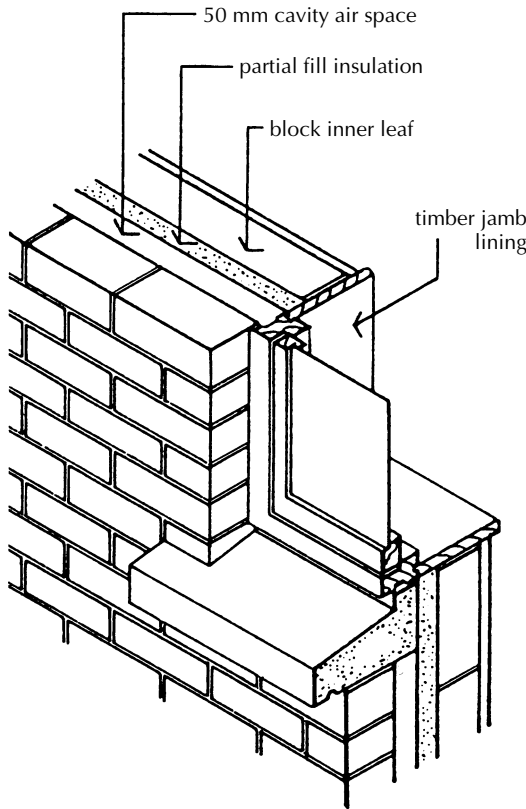
Figure 5.82   Jamb lining to wide cavity.

Head of openings in cavity walls

The brickwork and blockwork over the head of openings in cavity walls has to be supported by a lintel.

Steel lintels

Most loadbearing brick or blockwork walls over openings, where the cavity insulation is continued down to the head of the window or door frame, are supported by steel section lintels. The advantage of these lintels is that they are comparatively lightweight and easy to handle, they provide adequate support for walling over openings in small buildings and once they are bedded in place the work can proceed. The lintels are formed either from mild steel strip that is pressed to shape, and galvanised with a zinc coating to inhibit rust, or from stainless steel. The lintels for use in cavity walling are formed with either a splay to act as an integral damp-proof tray or as a top hat section over which a damp-proof tray is dressed. Typical sections are illustrated in Figure 5.83, also see Figure 5.63 and Photograph 5.2.
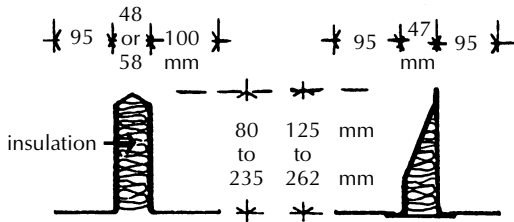
Figure 5.83   Lintels for cavity walls.

For insulation the splay section and top hat section lintels are filled with expanded polystyrene. The top hat section steel lintel is built into the jambs of both the inner and outer leaf to provide support for both leaves of the cavity wall, as illustrated in Figures 5.63 and 5.84. The two wings at the bottom of the lintel provide support for the brick outer and block inner leaves over the comparatively narrow openings for windows and doors. Where the cavity is partly filled with insulation it is usual to dress a flexible dpc from the block inner leaf down to a lower brick course or down to the underside of the brick outer leaf. The purpose of the damp-proof course or tray is to collect any water that might penetrate the outer leaf and direct it to weep holes in the wall.

The splay section lintel is built into the jambs of openings to provide support for the outer and inner leaf of the cavity wall over the openings, as illustrated in Figure 5.85. Where the cavity is filled with insulation there is no need to build in a damp-proof course or tray. Any water that might penetrate the outer
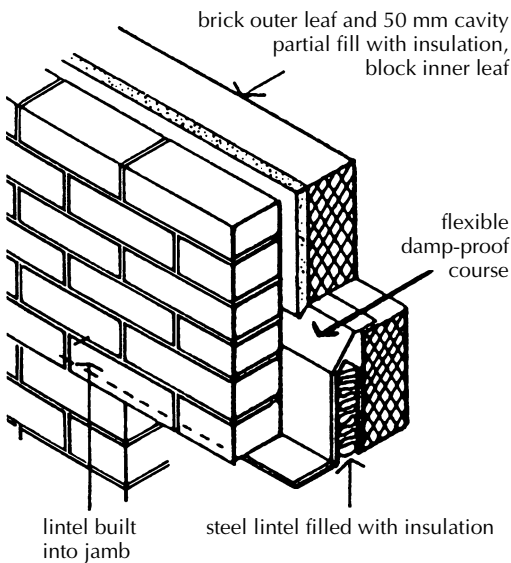
Figure 5.84   Top hat lintel.

brick outer leaf and
50 mm cavity filled
with insulation and
block inner leaf

lintel built
into jambs

steel lintel filled with insulation
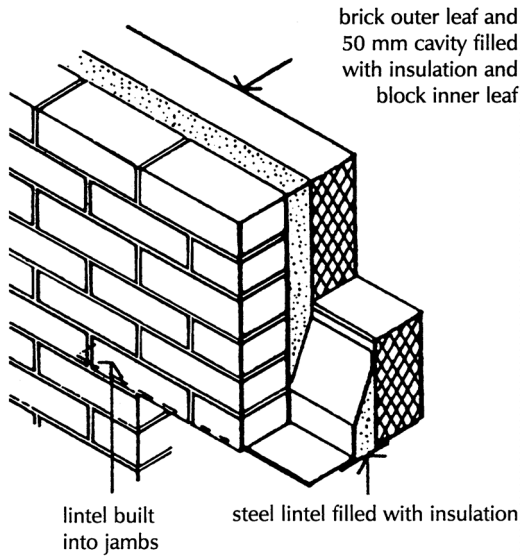
Figure 5.85   Splay lintel.

leaf will be directed towards the outside by the splay of the lintel. Unless the window or door frame is built-in or fixed with its external face close to the outside face of the wall, the edge of the wing of the lintel will be exposed on the soffit of the opening. Fairface brickwork supported by steel lintels may be laid as horizontal course brickwork or as a flat brick on edge or end lintel.

Concrete lintels

As an alternative to the use of steel lintels, reinforced concrete lintels may be used to support the separate leaves over openings (see Figure 5.86). A range of precast reinforced concrete lintels is available to suit the widths of most standard door and window openings with adequate allowance for building in the ends of lintels each side of openings. For use with fairface brickwork the lintel depth should match the depth of brick course heights to avoid untidy cutting of bricks around lintel ends. These comparatively lightweight lintels are bedded on walling as support for outer and inner leaves.

Cavity trays

In positions of severe exposure to wind driven rain, the outer leaf of a cavity wall may absorb water to the extent that rainwater penetrates to the cavity side of the outer leaf. It is unlikely, however, that water will enter the cavity unless there are faults in construction. Where the mortar joints in the outer leaf of a cavity wall are inadequately flushed up with mortar, or the bricks in the outer leaf are grossly porous and where the wall is subject to severe or very severe exposure, there is a possibility that wind driven rain may penetrate through

Section of window head and cill

External
environment

Internal
environment

Concrete block inner leaf

Insulation

Cavity

Cavity tie

dpm – cavity tray

**Head of opening
Lintel**

Cavity closer filled with
insulating material

Reinforced concrete
lintel

Reinforced concrete lintel

By using two separate concrete
lintels the heat does not flow
readily across the cavity

Can be made out of
reconstructed stone
lintel ('art stone'
lintel) or concrete
lintel with stone face
for aesthetics

Double or triple glazed window

Figure 5.86   Concrete lintels.

the outer leaf to the cavity. Where rain penetrates the outer leaf and enters the cavity, it is certain that either the construction of the wall is poorly executed, or the bricks have been unwisely chosen or the outer leaf is of inadequate thickness for the position of exposure in which it is built.

It has become common practice to build in some form of damp-proof course or tray of flexible, impermeable material to direct any water out to the external face of walls. A strip of polymer based polythene, bitumen felt or sheet lead is used for the purpose. The dpc and tray shown in Figure 5.86 is built in at the top of the inner lintel and dressed down to the underside of the outer lintel over the head of the window. As an alternative the dpc tray could be built in on top of the second block course and dressed down to the top of the outer lintel, with weep holes in the vertical brick joints.

Cavity wall insulation

Because the resistance to the passage of heat of a cavity wall by itself is poor, it is necessary to introduce a material with high resistance to heat transfer to the wall construction. Most of the materials, thermal insulators, that afford high resistance to heat transfer are fibrous or cellular, lightweight, have comparatively poor mechanical strength and are not suitable by themselves for use as part of the wall structure. The logical position for such material in a cavity wall, therefore, is inside the cavity.

Partial fill

This construction, which is described as partial fill insulation of cavity, requires the use of some insulating material in the form of boards that are sufficiently rigid to be secured against the inner leaf of the cavity. A 25 mm wide air space between the outer leaf and the cavity insulation should be adequate to resist the penetration of rain, providing the air space is clear of all mortar droppings and other building debris that might serve as a path for water. In practice, it is difficult to maintain a clear 25 mm wide air gap because of protrusion of mortar from joints in the outer leaf and the difficulty of keeping so narrow a space clear of mortar droppings. Good practice, therefore, is to use a 50 mm wide air space between the outer leaf and the partial fill insulation.

To meet insulation requirements and the use of a 100 mm cavity with partial fill insulation it may be economic to use a lightweight block inner leaf to augment the cavity insulation to bring the wall to the required U value. Usual practice is to build the inner leaf of the cavity wall first, up to the first horizontal row of wall ties, then place the insulation boards in position against the inner leaf. Then as the outer leaf is built, a batten may be suspended in the cavity air space and raised to the level of the first row of wall ties and the batten is then withdrawn and cleared of droppings. Insulation retaining wall ties are then bedded across the cavity to tie the leaves and retain the insulation in position and the sequence of operations is repeated at each level of wall ties. The suspension of a batten in the air space and its withdrawal and cleaning at each level of ties does considerably slow the process of brick and block laying.

Insulation retaining ties are usually plastic, standard galvanised steel or stainless steel wall ties to which a plastic disc is clipped to retain the edges of the insulation, as illustrated in Figure 5.87. The ties may be set in line one over the other at the edges of boards, so that the retaining clips retain the corners of four insulation boards. The materials used for partial fill insulation should be of boards, slabs or batts that are sufficiently rigid for ease of handling and to be retained in a vertical position against the inner leaf inside the cavity without sagging or losing shape, so that the edges of the boards remain close butted throughout the useful life of the building.
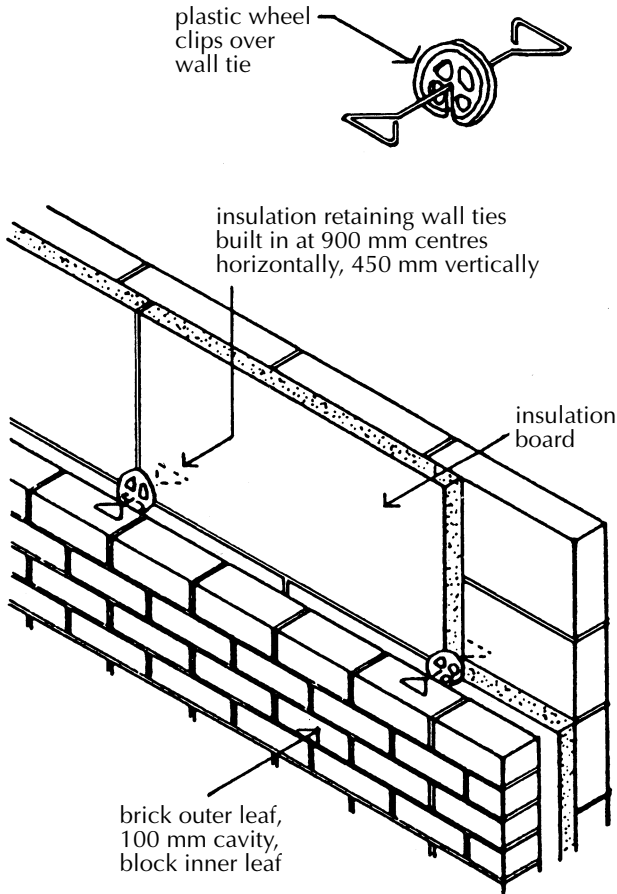
Figure 5.87   Partial fill cavity insulation.

Insulation materials

The materials used as insulation for the fabric of buildings may be grouped as inorganic and organic insulants.

Inorganic insulants are made from naturally occurring materials that are formed into fibre, powder or cellular structures that have a high void content as, for example, glass fibre, mineral fibre (rockwool), cellular glass beads, vermiculite, calcium silicate and magnesia or as compressed cork. Inorganic insulants are generally incombustible, do not support spread of flame, are rot and vermin proof and generally have a higher U value than organic insulants. The inorganic insulants most used in the fabric of buildings are glass fibre and rockwool in the form of loose fibres, mats and rolls of felted fibres and semi-rigid and rigid boards, batts and slabs of compressed fibres, cellular glass beads fused together as rigid boards, compressed cork boards and vermiculite grains.

Organic insulants are based on hydrdocarbon polymers in the form of thermosetting or thermoplastic resins to form structures with a high void content as, for example, polystyrene, polyurethane, isocyanurate and phenolic. Organic insulants generally have a lower U value than inorganic insulants, are combustible, support the spread of flame more readily than inorganic insulants and have a comparatively low melting point. The organic insulants most used for the fabric of buildings are expanded polystyrene in the form of beads or boards, extruded polystyrene in the form of boards and polyurethane, isocyanurate and phenolic foams in the form of preformed boards or spray coatings.

The materials used for cavity insulation are glass fibre, rockwool and EPS (expanded polystyrene), in the form of slabs or boards, in sizes to suit cavity tie spacing. With the recent increase in requirements for the insulation of walls it may well be advantageous to use one of the more expensive organic insulants such as XPS (extruded polystyrene), PIR (polyisocyanurate) or PUR (polyurethane) because of their lower U value, where a 50 mm clear air space can be maintained without greatly increasing the overall width of the cavity.

Insulation thickness

An approximate guide to the required thickness of insulation for a wall to achieve a U value of $0.35 \, W/m^2 \, K$ is to assume that the insulant provides the whole or a major part of the insulation. Using a 30 mm thick material with a U value of 0.02, a 46 mm thick material with a U value of 0.03, a 61 mm thick material with a U value of 0.04, a 76 mm thick material with a U value of 0.05, or a 92 mm thick material with a U value of $0.06 \, W/m^2 \, K$ will give approximately the same overall U value of $0.35 \, W/m^2 \, K$. The width of the cavity can be adjusted to suit the required thickness of insulation.

A more exact method is by calculation, as described:

$$\text{Thermal resistance required} = 1/0.35 = 2.86 \, m^2 \, K/W$$

Thermal resistance of construction is:

External surface	$0.06 \, m^2 \, K/W$
102 brick outer leaf	0.12
Cavity at least 50	0.18
115 block inner leaf	1.05
13 plasterboard	0.03
Inside surface	0.12
Total	**$1.56 \, m^2 \, K/W$**

Additional resistance to be provided by insulation $= 2.86 - 1.56 = 1.3 \, m^2 \, K/W$. Assuming that insulation with a U value of 0.03 is used, then the thickness of insulation required will be obtained by using the simple multiplication

1.3 × 0.03 × 1000 = 39 mm. So the required thickness of insulation is 39 mm, or the most convenient thickness available from a manufacturer, say 40 mm.

Total fill
Insulation that is built in as the cavity walls are raised, to fill the cavity totally, will to an extent be held in position by the wall ties and the two leaves of the cavity wall. To maintain a continuous, vertical layer of insulation inside the cavity one of the mineral fibre semi-rigid batts or slabs should be used. Fibreglass and rockwool semi-rigid batts or slabs in sizes suited to cavity tie spacing are made specifically for this purpose. As the materials are made in widths to suit vertical wall tie spacing there is no need to push them down into the cavity after the wall is built, as is often the procedure with loose fibre rolls and mats, and so displace freshly laid brick or blockwork.

The most effective way of insulating an existing cavity wall is to fill the cavity with some insulating material that can be blown into the cavity through small holes drilled in the outer leaf of the wall. The injection of the cavity fill is a comparatively simple job. The complication arises in forming sleeves around air vents penetrating the wall and sealing gaps around openings. Glass fibre, granulated rockwool of EPS beads are used for the injection of insulation for existing cavity walls. These materials can also be used for blowing into the cavity of newly built walls.

5.12 Timber

The word timber describes wood that has been cut for use in building. Timber has many advantages as a building material. It is a lightweight material that is easy to cut, shape and join by relatively cheap and simple hand or power operated tools in the production of wall, floor and roof panels, timber joists, and for rafters, walls, floors and roofs and joinery generally. As a structural material it has favourable weight to cost, weight to strength and weight to modulus of elasticity ratios and coefficients of thermal expansion, K values, density and specific heat. With sensible selection, fabrication and fixing and adequate protection it is a reasonably durable material in relation to the life of most buildings. Softwood and hardwood are terms used to classify different timber.

Properties of timber

Seasoning of timber
Up to two-thirds of the weight of growing wood is due to water in the cells of the wood. When the tree is felled and the wood is cut into timber this water begins to evaporate to the air around the timber, and the wood gradually shrinks as water is removed from the cell walls. As the shrinkage in timber is not uniform

the timber may lose shape and it is said to warp. It is essential that before timber is used in buildings, either it should be stacked for a sufficient time in the open air for most of the water in it to dry out, or it should be artificially dried out. If wet timber is used in building it will dry out and shrink and cause cracking of plaster and twisting of doors and windows. The process of allowing, or causing, newly cut wood to dry out is called seasoning, and timber that is ready for use in building is said to have been properly seasoned. The amount of water in wood varies, and it is not sufficient to allow all timber to dry out for some specific length of time, as one piece of timber may be well seasoned and dried out, while another similar piece stacked for the same length of time may still be too wet to use.

Moisture content of timber

It is necessary to specify that there shall be a certain amount of water, and no more or less, in timber suitable for building. Moisture content is stated as a percentage of the dry weight of the timber. The dry weight of any piece of timber is its weight after it has been so dried that further drying causes it to lose no more weight. This dry weight is reasonably constant for a given cubic measure of each type of wood and is used as the constant against which the moisture content can be assessed. Table 5.4 sets out moisture contents for timber. The moisture content of timber should be such that the timber will not appreciably gain or lose moisture in the position in which it is fixed in a building.

Natural dry seasoning

When logs have been cut into timbers they are stacked either in the open or in a rough open sided shed. The timbers are stacked with battens between them to allow air to circulate around them. The timbers are left stacked for a year or more, until most of the moisture in the wood has evaporated. Softwoods have to be stacked for a year or two before they are sufficiently dried out or seasoned, and hardwoods for up to ten years. The lowest moisture content of timber that can be achieved by this method of seasoning is about 18%.

Table 5.4   Moisture content of timber.

	1	2
Position of timber in building	**%**	**%**
External uses fully exposed	20 or more	–
Covered and generally unheated	18	24
Covered and generally heated	15	20
Internal and continuously heated building	12	20

Source: Column 1 Average moisture content likely to be attained in service conditions
Column 2 Moisture content which should not be exceeded in individual pieces at time of erection
Taken from BS 5268:Part 2:1996 (issue 2, May 1997)

Artificial or kiln seasoning

Because of the great length of time required for natural dry seasoning and because sufficiently low moisture contents of wood cannot be achieved, artificial seasoning is largely used today. After the wood has been converted to timber it is stacked with battens between the timber and they are then placed in an enclosed kiln. Air is blown through the kiln, the temperature and humidity of the air being regulated to effect seasoning more rapidly than with natural seasoning, but not so rapidly as to cause damage to the timber. If the timber is seasoned too quickly by this process it shrinks and is liable to crack and lose shape badly. To avoid this it is common practice to allow timber to season naturally for a time and then complete the process artificially as described.

Conversion of wood into timber

The method of cutting a log into timber will depend on the ultimate use of the timber. Most large softwood logs are converted into timbers of different sizes so that there is the least wastage of wood. Smaller softwood logs are usually converted into a few long rectangular section timbers. Most hardwood today is converted into boards.

The method of converting wood to timber affects the timber in two ways: (1) by the change of shape of the timber during seasoning and (2) in the texture and differences in colour on the surface of the wood. Because the spring wood is less dense than the summer wood the shrinkage caused when the wood is seasoned (dried) occurs mainly along the line of the annual rings. The circumferential shrinkage is greater than the radial shrinkage. Because of this the shrinkage of one piece of timber cut from a log may be quite different from that cut from another part of the log. This can be illustrated by showing what happens to the planks of a log converted by the 'through and through' cut method shown in Figure 5.88. When the planks have been thoroughly seasoned their deformation due to shrinkage can be compared by putting them together in the order in which they were cut from the log as in Figure 5.88. From this it will be seen that the plank, which was cut with its long axis on the radius of the circle of the log, lost shape least noticeably and was the best timber after seasoning. It is apparent that timber that is required to retain its shape during seasoning, such as good quality boarding, must somehow be cut as nearly as possible along the radius of the centre of the log. As it is not practicable to cut a log in the way we cut a slice out of an apple, logs, which are to be cut along their radius are first cut into quarters. Each quarter of the log is then cut into boards or planks. This can be done in a variety of ways. Two of the most economical ways of doing this are shown in Figure 5.88. It will be seen from these diagrams that one or two boards or planks are cut very near a radius of the circle, whilst the rest are cut somewhat off the radius and the former will lose shape least.
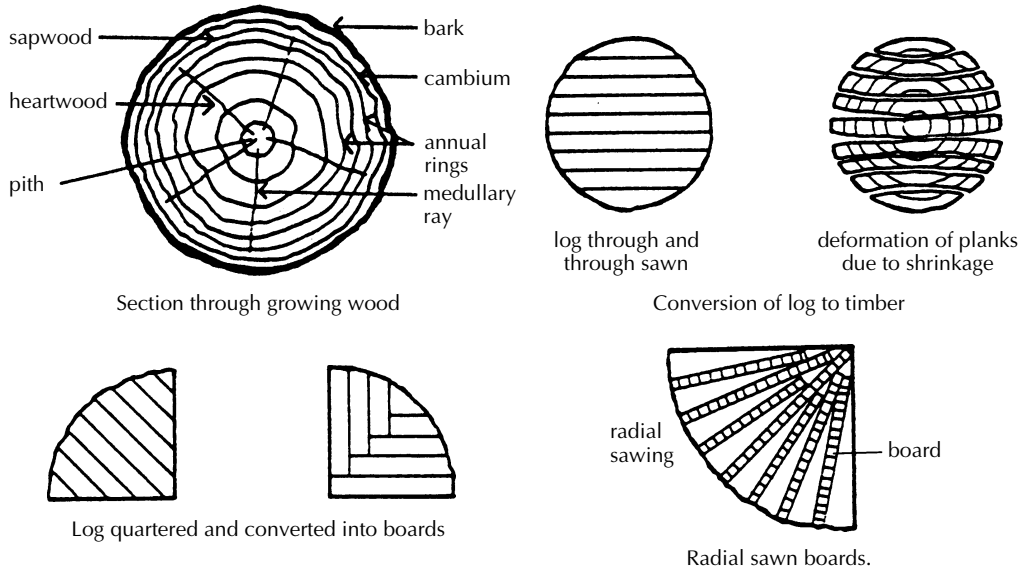
Figure 5.88   Conversion of wood into timber.

In describing the structure and growth of a tree, the medullary rays were described as being narrow radial lines of wood cells of different shape and structure from the main wood cells. If the face of a timber is cut on a radius of the circle of the log, the cells of the medullary rays may be exposed where the cut is made. With many woods this produces very pleasing texture and colour on the surface of the wood and it is said that the 'figure'of the wood has been exposed. To expose the figure of the wood by cutting along the medullary rays a quarter of a log has to be very wastefully cut, as shown in Figure 5.88. The radial cutting of boards as shown is very expensive and is employed only for high-class cabinet making and pannelling timbers where the exposed figure of the wood will be used decoratively.

Surface finishes for timber
There are three types of surface finish for wood: paint, varnish and stains. The traditional finishes, paint and varnish, are protective and decorative finishes that afford some protection against water externally and provide a decorative finish that can easily be cleaned internally. Paints are opaque and hide the surfaces of the wood, whereas varnishes are sufficiently transparent for the texture and grain of the wood to show. There is a wide range of stains available, from those that leave a definite film on the surface to those that penetrate the surface and range from gloss through semi-gloss to matt finish. The purpose of this finish is to give a selected uniform colour to wood without masking

the grain and texture of the wood. Most stains contain a preservative to inhibit fungal surface growth. These stains are most effective on rough sawn timbers.

Decay in timber

Fungal decay
Any one of a number of wood-destroying fungi may attack timber that is persistently wet and has a moisture content of over 20%.

Dry rot
This is the most serious form of fungal decay and is caused by *Serpula lacrymans* which can spread and cause extensive destruction of timber. The description dry rot derives from the fact that timber that has been attacked appears dry and powdery. The airborne spores of this fungus settle on timber and if its moisture content is greater than 20% they germinate. The spore forms long thread-like cells which pierce the wood cells and use the wood as a food. The thread-like cells multiply, spreading out long white thread-like arms called mycelium, which feed on other wood cells. This fungus can spread many tens of feet from the point where the spore first began to thrive, and is capable of forming thick greyish strands that can find their way through lime mortar and softer bricks. Timber that is affected by this fungus turns dark brown and shrinks and dries into a cracked powdery dry mass. It is generally accepted that there is little risk of fungal decay in softwood if the timber is maintained at a moisture content of 20% or less.

Prevention of dry rot
Do not use unseasoned timber in buildings. Prevent seasoned timber becoming so wet that it can support the fungus by:

❑ Building in a good horizontal dpc
❑ Either ventilating the space below or around timber floors or by designing the building so that these spaces do not become damp
❑ Immediately repairing all leaking water, rainwater and drain pipes that otherwise might saturate timber to such an extent as to make it liable to dry rot

Replacement of timber affected by dry rot
The cause of the persistent dampness that has raised the moisture content of timber above 20%, such as leaking gutters or water pipes, must be corrected. Timber which has been affected by the fungus or is in close proximity to it should be taken out or cut out of the building, and this timber should be burnt immediately. The purpose of burning the affected timber is to ensure that none of it is used in the repairs and to kill any spore that might cause further rot.

All walls on which, or against which, the fungus grew must be thoroughly cleaned and sterilised by application of a fungicidal solution. Any old lime plaster on which or through which the rot has spread should be hacked off and renewed. New timber used to replace affected timber should be treated with a wood preservative before it is fixed or built in.

Wet rot

Wet rot is caused principally by *Coniphora puteana*, the cellar fungus, which occurs more frequently, but is less serious, than dry rot. Decay of timber due to wet rot is confined to timbers that are in damp situations such as cellars, ground floors without dpcs and roofs. The rot causes darkening and longitudinal cracking of timber and there is often little or no visible growth of fungus on the surface of timber.

Prevention of wet rot

Timber should not be built into or in contact with any part of the structure that is likely to remain damp. Damp-proof courses and damp-proof membranes above and at ground level and sensibly detailed flashings and gutters to roofs and chimneys will prevent the conditions suited to the growth of wet rot fungus. Affected timber should be cut out and replaced by sound new timber treated with a preservative. It is not necessary to sterilise brickwork around the area of affected timber.

Insect attack on wood

In this country the three sorts of insect which most commonly cause damage to timber are the furniture beetle, the death-watch beetle and the house longhorn beetle. Timber which the larvae of these beetles have affected should be sprayed or painted with a preservative that contains an insecticide during early summer and autumn. These preservatives prevent the larvae changing to beetles at the surface of the wood and so arrest further infestation.

Wood preservatives

Wood may be preserved as a precaution against fungal decay or insect attack. There is very little likelihood of softwood timber in buildings, which are maintained at a moisture content below 20 to 22%, being affected by fungal attack and little possibility of attack by beetles. Current practice is based on the premise that prevention is better than cure. Where it is decided to adopt preservation, the two types of preservative in general use are water borne or organic solvent formulations where water or a volatile solvent serves as a vehicle for the active fungicide or insecticide components.

Water borne preservatives
The most commonly used water borne preservative is based on solutions of copper sulphate, sodium dichromate and arsenic pentoxide, abbreviated to

CCA. The liquid preservative is applied by pressure in a pressure tank. The degree to which a water borne preservative will penetrate timber depends on the species. A lateral penetration of 6 to 19 mm in about 2 to 3 hours occurs under pressure with European Redwood and 3 to 6 mm with Canadian Douglas Fir, for example.

To gain the maximum advantage of preservation, all timber should be cut and notched as necessary before preservative treatment. Any cutting after treatment, particularly where the cutting penetrates below the surface penetration, should be treated with preservative. Preservation with a water borne preservative causes a considerable increase in the moisture content of the timber, an increase in the cross-section and a rise in the surface grain. After preservation, timber has to be dried to the required moisture content. Water borne CCA preservatives are most suited for use with sawn structural timbers such as floor joists, roof rafters and stud framing where the raised grain of the wood is of no consequence.

Organic solvent preservation
These preservative solutions comprise an organic solvent such as white spirits with fungicides such as pentachlorophenol and zinc naphthenate. An insecticide is added as required. The liquid preservative is applied by double vacuum process and by immersion. The organic solvent evaporates to air, leaving the fungicide in the wood to the depth of penetration depending on the species of wood. An organic solvent is commonly used for cut joinery sections both plain and moulded because the solvent dries quickly, does not cause an increase in section and does not noticeably affect the surface of the prepared joinery sections.

Tar oil preservatives
Tar oil preservatives, such as creosote, are used for the preservation of wood used for fences where the strong smell of this material is not offensive. Because of the appreciable additional cost in the preservative treatment of timber it should be used sparingly where there is a real risk of fungal or insect attack.

5.13 Timber framed walls

The construction of a timber-framed wall is a rapid, clean, dry operation. The timbers can be cut and assembled with simple hand or power operated tools and once the wall is raised into position and fixed it is ready to receive wall finishes. A timber-framed wall has adequate stability and strength to support the floors and roof of small buildings, such as houses. Covered with wall finishes, such as plasterboard, it has sufficient resistance to damage by fire, good thermal insulating properties and reasonable durability providing it is sensibly constructed and protected from decay. Two workers in a matter of a few days

can construct a timber-framed house on site. Alternatively, off-site prefabrication allows the erection of a house within a day, with roofing and external cladding completed soon afterwards.

Modern methods of timber frame construction were introduced into the UK in the 1960s. Timber frame construction offers flexible planning, energy efficient construction, economic use of materials and a wide range of finishes. Timber frame construction, especially when light cladding is used, is lighter than a comparable masonry construction and in some instances foundations can be designed to be smaller and hence less wasteful of materials. The dry construction is fast and there is no need to wait for wet trades to dry out before decorating. The high levels of thermal insulation make timber frame an attractive option given the more stringent thermal requirements as set out in the Approved Documents. The structure of timber frame buildings must be designed by a structural engineer to demonstrate structural stability of the structure and compliance with the Building Regulations. It is common to erect buildings to a height of two or three storeys, although it is possible to build higher (six to eight storeys) and still satisfy the Building Regulations.

Strength and stability of timber

The strength of timber varies with species and is generally greater with dense hardwoods than less dense softwoods. Strength is also affected by defects in timber such as knots, shakes, wane and slope of the grain of the wood.

Stress grading of timber

Stress grading of structural timbers, which was first adopted in the Building Regulations 1972, is now generally accepted in selecting building timber. There are two methods of stress grading: visual grading and machine grading.

Visual grading

Trained graders determine the grade of a timber by a visual examination from which they assess the effect on strength of observed defects such as knots, shakes, wane and slope of grain. There are two visual grades, general structural (GS) and special structural (SS), the allowable stress in SS being higher than in GS.

Machine grading

Timbers are subjected to a test for stiffness by measuring deflection under load in a machine that applies a specified load across overlapping metre lengths to determine the stress grade. This mechanical test, which is based on the fact that strength is proportional to stiffness, is a more certain assessment of the true strength of a timber than a visual test. The machine grades, which are comparable to the visual grades, are machine general structural (MGS) and
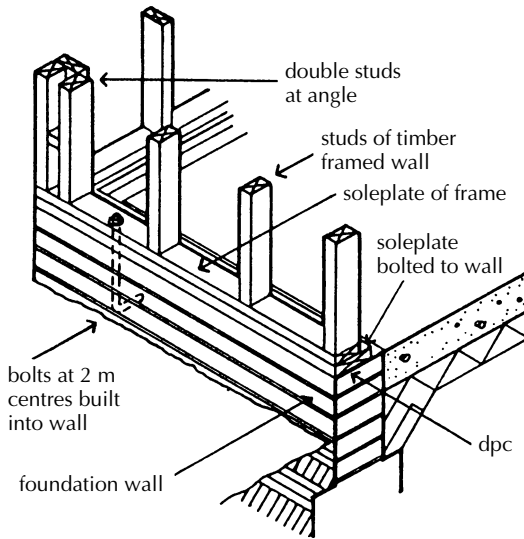
Figure 5.89   Base of timber framed wall.

machine special structural (MSS). There are, in addition, two further machine grades: M50 and M75. The stress of M50 lies between MGS and MSS and M75 is the highest stress grade in the series.

Stress graded timbers are marked GS and SS at least once within the length of each piece for visually graded timber together with a mark to indicate the grader or company. Machine graded timber is likewise marked MGS, M50, MSS and M75 together with the BS kitemark and the number of the British Standard, 4978. Approved Document A, which gives practical guidance to meeting the requirements of the Building Regulations for small buildings, includes tables of the sizes of timber required for floors and roofs, related to load and span.

Stability
The stability of a timber-framed wall depends on a reasonably firm, stable foundation on which a stable structure can be constructed. Figure 5.89 is an illustration of the base of a timber framed wall set on a brick upstand raised from a strip foundation. The 150×50 mm timber sole plate is bedded on a horizontal dpc, with 13 mm bolts at 2 m centres built into the wall to anchor the plate against wind uplift. As an alternative the bolts may be shaped so that the bottom flange is built into the wall, run up on the inside face of the wall with a top flange turned over the top of the plate.

Where a concrete raft serves as foundation, the upstand kerb of the raft serves as a base for the timber wall with the anchor bolts set into the concrete curbs and turned over the top of the sole plate. The vertical 100×50 mm studs are

dpc turned up behind sole
plate and laps with vertical
vapour control to improve
airtightness

Vapour control layer under
timber floor

Cavity ties

Insulation between studs

Plywood sheathing

Sole plate fixed to concrete
raft
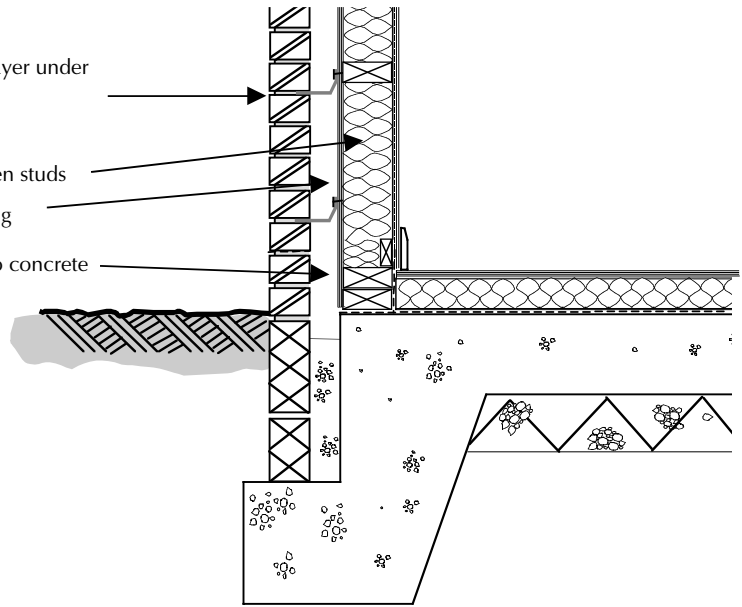
Figure 5.90   Timber framed wall on raft foundation.

nailed to the sole plate at 400 to 600 mm centres with double studs at angles to facilitate fixing finishes (illustrated in Figure 5.90).

A timber stud wall consists of small section timbers fixed vertically between horizontal timber head and sole plates, as illustrated in Figure 5.89. The vertical stud members are usually spaced at centres of 400 to 600 mm to support the anticipated loads and to provide fixing for external and internal linings. The horizontal noggins fixed between studs are used to stiffen the studs against movement that might otherwise cause finishes to crack. A face of plywood sheeting is often applied to both sides of the insulated stud panel, thus providing considerable lateral stability.

By itself a timber stud wall has poor structural stability along its length because of the non-rigid, nailed connection of the studs to the head and sole plate, which will not strongly resist racking deformation. A timber stud wall must, therefore, be braced (stiffened) against racking. As an internal wall or partition a timber stud frame may be braced by diagonal timbers or by being wedged between solid brick or block walls. As an external wall a timber stud frame may be braced between division walls and braced at angles where one wall butts to another, as illustrated in Figure 5.91. Diagonally fixed boarding or plywood sheathing fixed externally as a background for finishes braces an external stud frame wall.
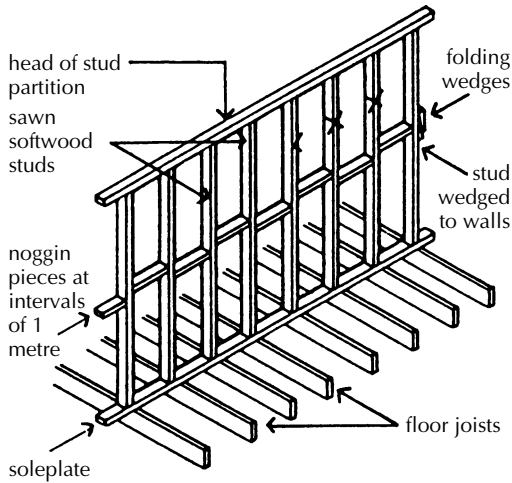
Figure 5.91   Timber stud frame.

Because of its small mass, a timber frame wall has poor lateral stability against forces such as wind that tend to overturn the wall. For stability along the length of the wall, connected external and internal walls or partitions will serve as buttresses. For stability up the height of the wall, timber upper floors and the roof connected to the wall will serve as buttresses. Buttressing to timber walls that run parallel to the span of floor joists and roof frames is provided by steel straps that are fixed across floor joists and roof rafters and fixed to timber
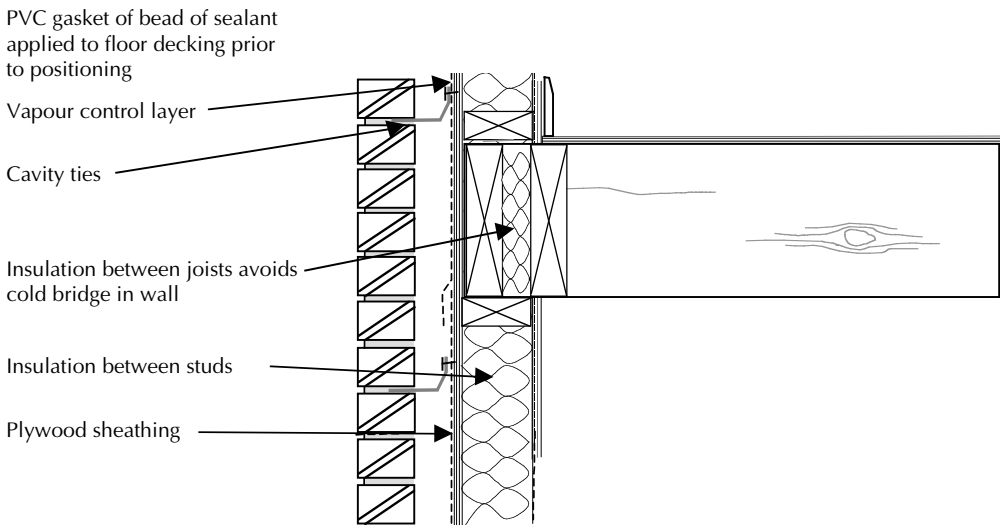
Figure 5.92   Support for floor joists.

walls in the same way that straps are used to buttress solid walls as previously described.

The usual method of supporting and fixing the upper floor joists to the timber wall frame is by using separate room height wall frames. The heads of the ground floor frames provide support for the floor joists on top of which the upper floor wall frame is fixed, as illustrated in Figure 5.92. The roof rafters are notched and fixed to the head of the upper floor wall frame. As an alternative, a system of storey height wall frames may be used with the top of the head of the lower frame in line with the top of the floor joists that are supported by a timber plate nailed to the studs, as illustrated in Figure 5.93. The upper frame

Joists notched over
timber bearer

Vapour control layer
under timber floor

Cavity ties

Insulation between joists
avoid cold bridge in wall

Insulation between
studs

Plywood sheathing

Alternatively a joist
hanger can be used
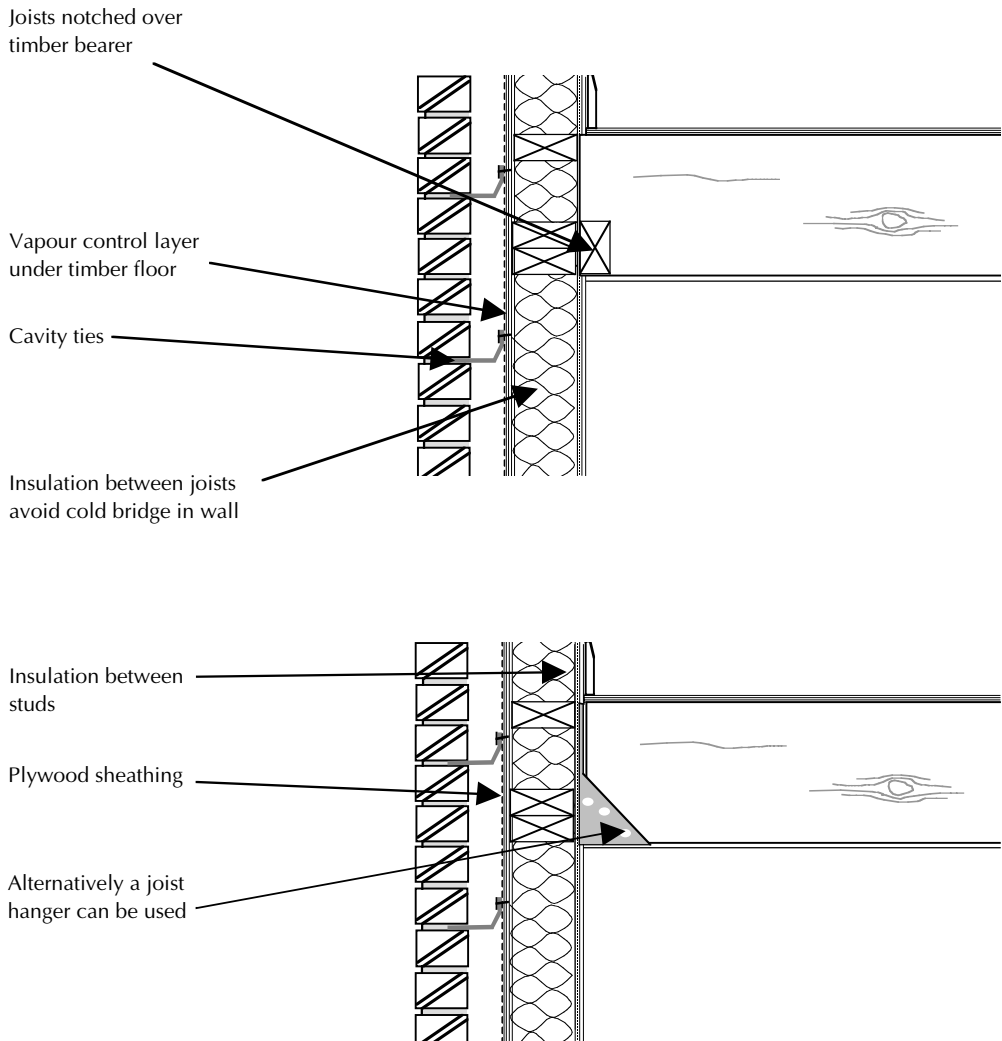
Figure 5.93   Timber framed wall.

is formed on the lower frame. The advantage of this system is that there is continuity of the wall frame and the disadvantage is that there is a less secure connection and therefore lateral bracing.

Resistance to weather

The traditional weather envelope for timber walls is timber weatherboarding nailed horizontally across the stud frame. The weather boards are shaped to overlap to shed water. Some typical sections of boarding are illustrated in Figure 5.94. The wedge section, feather edge boarding, is either fixed to a simple overlap or rebated to lie flat against the studs as illustrated. The shaped chamfered and rebated and tongued and grooved shiplap boarding is used for appearance sake, particularly when the boarding is to be painted for protection and decoration. To minimise the possibility of boards twisting it is practice to use boards of narrow widths of as little as 100 and usually 150 mm.

As protection against rain and wind penetrating the weatherboarding it is usual to fix sheets of roofing underlay or breather paper behind the weatherboarding. Breather paper serves to act as a barrier to water and at the same time allow the release of moisture vapour under pressure to move through the sheet.
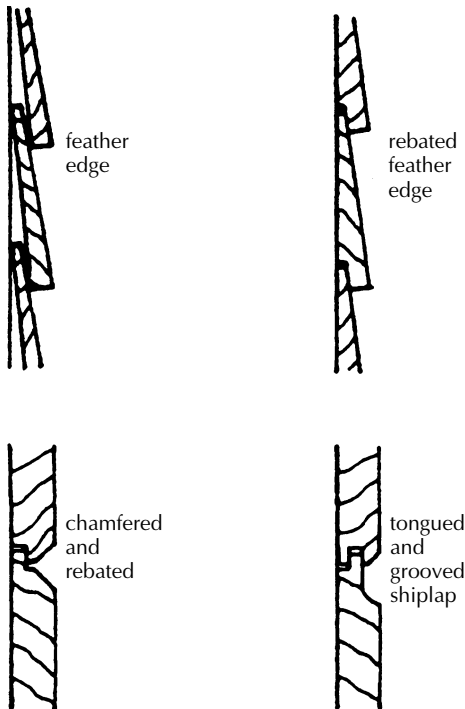
Figure 5.94   Timber weatherboarding.
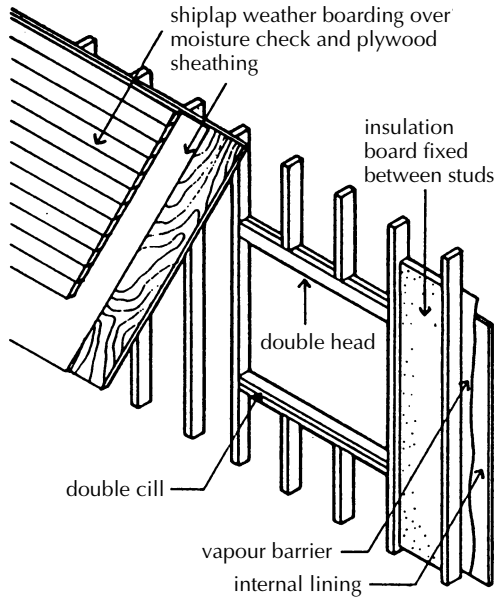
Figure 5.95 Weather envelope.

Instead of nailing weatherboarding directly to the studs of the wall frame it is usual to fix either diagonally fixed boarding or sheets of plywood across the external faces of the stud frame. The boarding and ply sheets serve as a brace to the frame and as a sheath to seal the frame against weather. Figure 5.95 is an illustration of weatherboarding fixed to plywood sheathing with insulation fixed between studs.

Around openings to windows and doors the weatherboarding and ply sheath may be butted to the back of window and door frames fixed to project beyond the stud frames for the purpose. At the head of the opening the head of the frame may be reduced in depth so that the boarding runs down over the face of the frame. The weatherboarding butts up to the underside of a projecting cill. For extra protection sheet lead may be fixed behind the weatherboarding and nailed and welted to window and door frames. At external angles the weatherboarding may be mitred or finished square edged. As a seal and finish to the joint between the weatherboarding at external angles timber cover mouldings have been used without much success as the mouldings soon become saturated, swell and defeat the object of their use. A more straightforward and effective weathering is to fix a strip of lead behind the weatherboarding to form a sort of secret gutter. In exposed positions weatherboarding may not provide adequate protection.

Tile or slate hanging may be used to provide more durable protection. In the UK it has been common practice in speculative house construction to provide

the weather protection with a brick outer leaf. This seemingly perverse form of construction, which combines 'wet trade' construction with a 'dry trade', may be justified by the permanence and appearance of an outer brick wall. A sensible argument for this odd form of construction could be speed of erection and completion of building work by combining the rapid framing of a timber wall, floor and roof structure that could be completed and covered in a matter of a few days, with a brick outer leaf and speedy installation of electrical, water and heating services and dry linings. Figure 5.96 is an illustration of a two-storey house with timber walls, floor and roof with a brick outer leaf.

For strength the timber inner leaf, floor and roof are adequate to the small loads. For stability the upper floor and roof are adequate to stiffen the walls. It could be demonstrated that the external brick outer leaf, buttressed at angles, has sufficient stability by itself, or the use of ties across the cavity at first floor level and roof to the timber structure could be used to augment stability if need be.

For resistance to weather, a brick outer leaf is generally accepted as being thick enough to prevent penetration of rain to the inside.

For thermal resistance one of the thermal insulation boards is fixed to a vapour check and plywood sheathing nailed to the stud frame. The thermal insulation is carried up in the cavity to unite with the roof insulation laid on a vapour check. The plywood sheathing is used to brace the stud frame diagonally.

Internal plasterboard linings to the timber framed walls, the soffit of the first floor and the ceiling will provide a sufficient period of fire resistance to meet the requirements for a two floor house. The requirement for barriers in external cavity walls to small houses applies only to the junction of a cavity and a wall separating buildings.

Prefabricated timber frames

Stick build
Using this traditional technique, the timber walls and floors are simply assembled from the individual members and components. Although not pre-assembled, the timber members are often delivered to site pre-cut and identified for ease of assembly. Apart from small, self-build and/or complicated structures, stick-build is rarely used.

Platform frame
With the use of a wide range of wood working tools that are available it is practice to prefabricate timber wall frames, particularly in North America and Scandinavia where there is a plentiful supply of timber and a traditional use of timber for small buildings. The advantage of using frames that are fabricated either on or off site complete with outer and inner finishes is speed of erection.
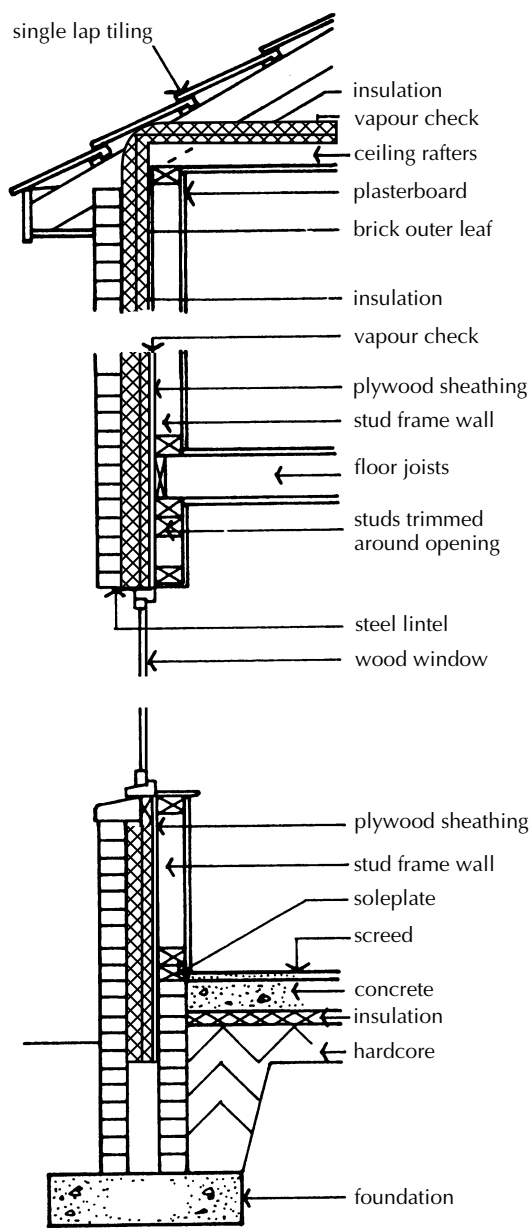
Figure 5.96 Brick outer and timber framed cavity wall.

Where a number of houses are to be built it is possible to complete a building in a matter of days. The systems most used are either platform or storey frames. (The term platform frame equally applies to light steel frame house construction made from cold-formed steel sections.)
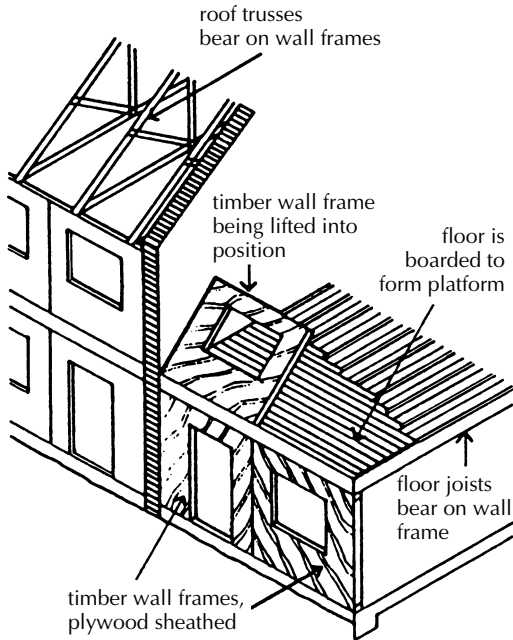
Figure 5.97   Platform frame.

The platform frame system of construction employs prefabrication frames that are floor to ceiling level high, with the sole of the lower stud frame bearing on the foundation and the head of the frame supporting first floor joists, as illustrated in Figure 5.97. The first floor can then be used as a working platform from which the upper frames are set on top of the lower. The wall frames or panels may be the full width of the front and rear walls of narrow terrace houses or made in two or more panels. The first floor joists and roof provide sufficient bracing up the height and the separating wall will brace across the width of the wall. The wall frames may be prefabricated as stud frames sheathed with plywood or made complete with finishes both sides.

Balloon frames
The term balloon frames also applies to steel frame housing (light steel – cold formed sections). Storey frames (balloon frames) are made the height of a storey, floor to floor so that the top of the head of a frame is level with the top of the floor joists. A bearer fixed to the stud frame supports the joists. This arrangement provides continuity of the stud framing up the height of the wall at the expense of some loss of secure anchor of floor joists to wall. A balloon wall frame is fabricated as one continuous panel the height of the two floors of small houses, as illustrated in Figure 5.98. The advantage of the balloon frame is speed of

rafters bear on wall frames

continuous studs

joist nailed to side of stud

ledger

floor joists nailed to studs

full height wall frame plywood sheathed
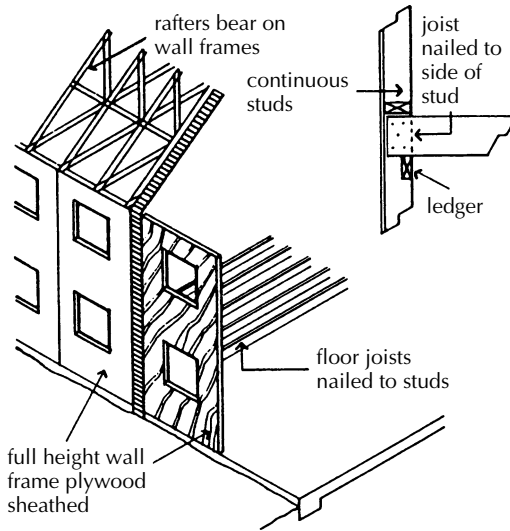
Figure 5.98   Balloon frame.

fabrication and erection, and the least number of joints between frames that have to be covered and weathered externally.

Functional requirements specific to timber frames

Fire safety

The requirements for means of escape from one or two storey houses are that each habitable room either opens directly on to a hallway or stair leading to the entrance, or that it has a window or door through which escape could be made and that means are provided for giving early warning in the event of fire. With increased height and size, where floors are more than 4.5 m above ground, it is necessary to protect internal stairways or provide alternative means of escape. Where windows and doors may be used as a means of escape, their minimum and maximum size and the minimum and maximum height of the window cill are defined.

Specifying a minimum period of fire resistance for the elements of structure restricts the premature failure of the structural stability of a building. A timber framed wall covered with plasterboard internally satisfies the requirement for houses of up to two storeys. To prevent the spread of fire between buildings, limits to the size of 'unprotected areas' of walls and finishes to roofs close to boundaries are set out in the Building Regulations. By reference to the boundaries of the site, the control will limit spread of fire. Unprotected areas are those parts of external walls that may contribute to spread of fire and include glazed windows, doors and those parts of a wall that may have less than a notional fire resistance. Limits are set on the use of roof coverings that will not provide

adequate protection against the spread of fire across their surface to adjacent buildings.

Resistance to the passage of heat
Timber is a comparatively good insulator. However, the sections of a timber frame do not by themselves generally afford sufficient insulation to meet the requirements of the Building Regulations and a layer of some insulating material has to be incorporated in the construction. The layer of insulation is fixed either between the vertical studs of the frame or on the outside or inside of the framing. The disadvantage of fixing the insulation between the studs is that there may be a deal of wasteful cutting of insulation boards to fit them between studs and to the extent that the U value of the timber stud is less than that of the insulation material, there will be a small degree of thermal bridge across the studs. The advantage of fixing the insulation across the outer face of the timber frame is simplicity in fixing and the least amount of wasteful cutting. Also, the void space between the studs will augment insulation and provide space in which to conceal service pipes and cables. The disadvantage of external insulation is that the weathering finish such as weatherboarding has to be fixed to vertical battens screwed or nailed through the insulation to the studs. Unless the insulation is one of the rigid boards it may be difficult to make a fixing for battens sufficiently firm to nail the battens to. Internal insulation is usually in the form of one of the insulation boards that combine insulation with a plasterboard finish.

Vapour check
A high level of insulation required for walls may well encourage moisture vapour held by warm inside air, particularly in bathrooms and kitchens, to find its way due to moisture vapour pressure into a timber framed wall and condense to water on the cold side of the insulation. The condensation moisture may then damage the timber frame. As a barrier to warm moist air there should be some form of vapour check fixed on the warm side of the insulation. Closed cell insulating materials such as extruded polystyrene, in the form of rigid boards, are impermeable to moisture vapour and will by themselves act as a vapour check. The boards should either be closely butted together or supplied with rebated or tongued and grooved edges so that they fit tightly and serve as an efficient vapour check.

Where insulation materials that are pervious to moisture vapour, such as mineral fibre, are used for insulation between studs, a vapour check of polythene sheet must be fixed right across the warm side of the insulation. The polythene sheet should be lapped at joints and continued up to unite with any vapour check in the roof and should, as far as practical, not be punctured by service pipes. Electrical cables that are run through the members of a timber wall and the insulation between the studs may overheat due to the surrounding

insulation, with a risk of short circuit or fire. To prevent overheating of cables run through insulation, the cables should be de-rated by a factor of 0.75 by using larger cables than specified, which will generate less heat. So that cables are not run through insulation it is wise to fix the inside dry lining to timber frames that are filled with insulation onto timber battens nailed across the frame, so that there is a void space in which cables can be safely run.

Insulation for timber walls
The inorganic materials glass fibre and rockwool are most used for insulation between studs as there is no advantage in using the more expensive organic materials, as the thickness of insulation required is not usually greater than the width of the studs. Either rolls of loosely felted fibres or compressed semi-rigid batts or slabs of glass fibre or rockwool are used. The material in the form of rolls is hung between the studs where it is suspended by top fixing and a loose friction fit between studs, which generally maintains the insulating material in position for the comparatively small floor heights of domestic buildings. The friction fit of semi-rigid slabs or batts between studs is generally sufficient to maintain them, close butted, in position. For insulating lining to the outside face of studs one of the organic insulants such as XPS or PIR provides the advantage of least thickness of insulating material for a given resistance to the transfer of heat. The more expensive organic insulants, in the form of boards, are fixed across the face of studs for ease of fixing and to save wasteful cutting. A vapour check should be fixed on to or next to the warm inside face of insulants against penetration of moisture vapour. Organic insulants, such as XPS, which are substantially impervious to moisture vapour, can serve as a vapour check, particularly when rebated edge boards are used and the boards are close butted together.

Resistance to the passage of sound
The small mass of a timber framed wall affords little resistance to airborne sound, but does not readily conduct impact sound. The insulation necessary for the conservation of heat will give some reduction in airborne sound and the use of a brick or block outer leaf will appreciably reduce the intrusion of airborne sound.

5.14 Steel frame wall construction

Although steel is traditionally associated with large commercial and industrial buildings, light gauge steel (cold formed steel sections) are being used in house construction. The sections of steel are used in a similar way to timber. The rolled steel sections can be assembled using either stick, panel or balloon construction. When using stick construction the individual members are delivered to site

pre-cut, pre-punched for holes to be cut or self-tapping screws to be used. Advantages of stick-build construction are:

❏ Slight modifications on sight can be accommodated
❏ Adjustments can be made so that site tolerances can be achieved
❏ The structural members can be packed and transported in small tightly packed loads

Stick build construction is labour intensive and is not therefore widely used.

The panel construction has the advantage that the wall sub-frames, panels, floors and roof trusses are prefabricated and delivered to site ready assembled. The sub-frames and panels are connected on site using bolts or self-tapping screws. The main advantages of panel construction are:

❏ Large prefabricated sections – saving labour time
❏ Speed of erection
❏ Good quality control achieved in factory production
❏ Accuracy of the components and panels make them easy to assemble on site.

In balloon construction the panels are much larger, floor to roof, but the components are much the same as panel frame construction. Because the steel frame is a good conductor of heat it is important that the insulation is not placed between the metal frame, but is applied to the inside of the cavity (see *Barry's Advanced Construction of Buildings* for further information).

5.15 Internal and party walls

Internal walls may either be loadbearing or non-loadbearing. Non-loadbearing walls are usually referred to as 'partition' walls, although care is required because the term is used very loosely. In loadbearing masonry construction the internal walls were usually constructed from brick or blockwork, although more recently the trend has been to use stud walls made of timber or metal, which are quicker to erect and easier to move at a future date (Figure 5.99).

Party walls

The requirement of Part E of Schedule 1 to the Building Regulations is that walls that separate a dwelling from another building or from another dwelling shall have reasonable resistance to airborne sound. Where solid walls of brick or block are used to separate dwellings, the reduction of airborne sound between dwellings depends mainly on the weight of the wall and its thickness. A cavity wall with two leaves of brick or block does not afford the same sound reduction
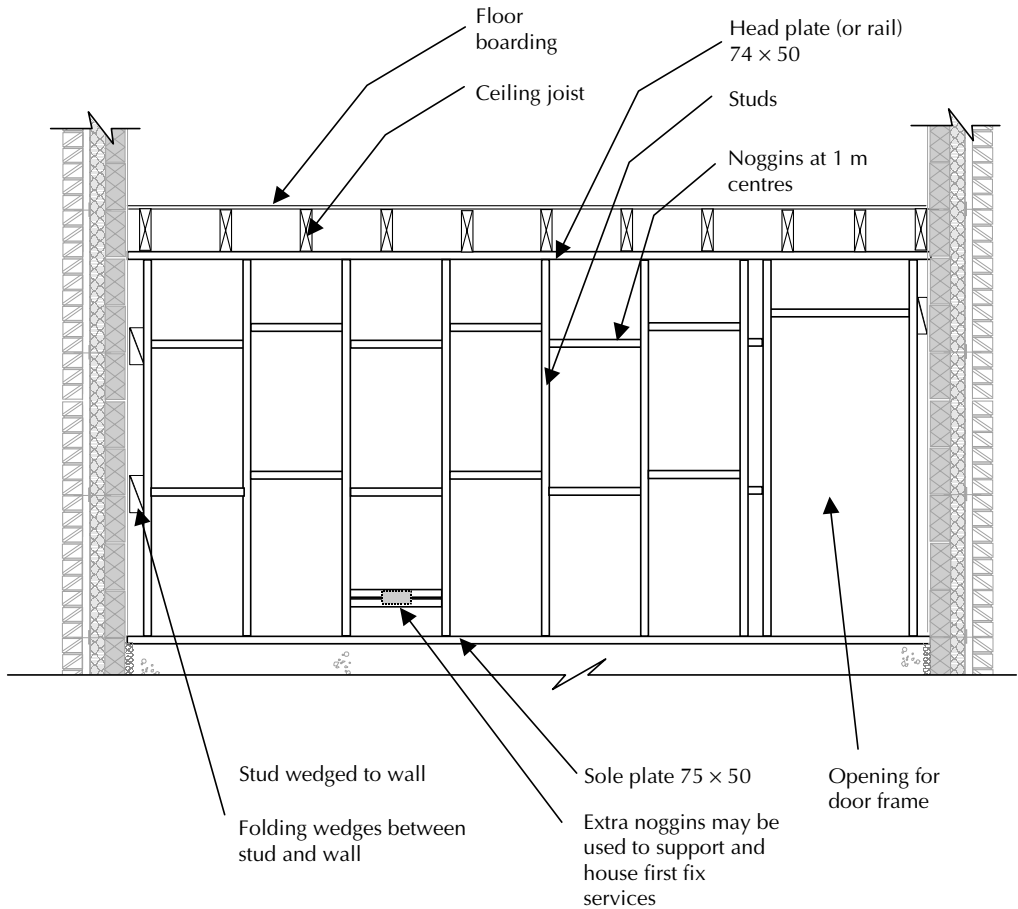
Figure 5.99   Timber stud partition wall.

as a solid wall of the same equivalent thickness because the stiffness of the two separate leaves is less than that of the solid wall and, in consequence, is more readily set into vibration. The joints between bricks or blocks should be solidly filled with mortar and joints between the top of a wall and ceilings should be filled against airborne sound transmission.

Approved Document E provides practical guidance to meeting the requirements of the Building Regulations in relation to walls between dwellings by stipulating the minimum weight of walls to provide adequate airborne sound reduction. For example, a solid brick wall 215 mm thick, plastered both sides, should weigh at least 300 kg/m^2 including plaster, and a similar cavity wall 255 mm thick, plastered both sides, should weigh at least 415 kg/m^2 including plaster, and a cavity block wall 250 mm thick, plastered both sides, should weigh at least 425 kg/m^2, including plaster.

Care should be taken to ensure that the wall and surrounding structure is suitable to achieve the level of sound insulation required. Consideration needs to be given to impact sound, sealing air paths (to prevent airborne sound) and controlling flanking transmission.

While the walls may not separate the internal and external environment, consideration still needs to be given to thermal insulation in separating walls. Comfort levels are individual and neighbours may want to maintain adjoining rooms at different temperatures.

In flats and houses separated by party walls it is essential that fire is restricted from passing from one dwelling to another. The Building Regulations outline the requirements of compartment walls (walls that restrict the passage of fire from one area to another).

The Party Wall Act 1996 provides a framework of statutory regulations that must be complied with when undertaking works that affect adjoining property. The three main issues that are addressed are: the construction of new walls on boundaries between adjoining owners' land (section 1: New building on junction); repairs and modification to existing party walls (section 2: Repair etc. of party wall: rights of owner); and excavation near to the neighbouring buildings or property (section 6: Adjacent excavation and construction). In order to comply with the Act, a notice must be served on adjoining owners if works covered by the Act, such as work to party walls or boundaries, are planned. Where there is disagreement between owners, the parties are required to resolve the matter through a dispute resolution procedure.

6 Roofs

The roof is an important element in providing protection from the weather and has a significant role to play in the reduction of heat loss from a building. Roofs are classified as being either pitched or flat. Timber is the most common material used, with some use of concrete for flat roofs. Although it is common practice to construct pitched roofs from pre-fabricated timber trusses, space has been reserved for the traditional timber roof built on site, primarily as an aid to the understanding of construction and terminology, but also as an aid to those involved in repair and refurbishment projects. However, more traditional methods of roof construction may return as the value of habitable space increases and rooms within the roof space become more common.

6.1 Functional requirements

The functional requirements of a roof are:

- Strength
- Stability
- Resistance to weather
- Durability and freedom from maintenance
- Fire safety
- Resistance to the passage of heat
- Resistance to the passage of sound
- Resist air leakage
- Security
- Aesthetics

Strength and stability
The strength and stability of a roof depends on the characteristics of the materials from which it is constructed and the way in which the materials are formed as a horizontal (flat) platform or as a triangular (pitched) framework.

The strength and stability of a flat roof depends on adequate support from walls or beams and sufficient depth or thickness of timber joists. Whether it is made of timber, concrete or steel, the roof should not suffer excessive deflection under the dead load of the roof itself and the load of snow and wind pressure or uplift that it may suffer.

The construction of a pitched roof relies on triangular frames of sloping rafters tied (trussed) together with horizontal ceiling joists, usually with a

symmetrical pitch

asymmetrical pitch

monopitch with
trussed rafter

butterfly roof

monopitch with
sloping soffit

lean-to roof
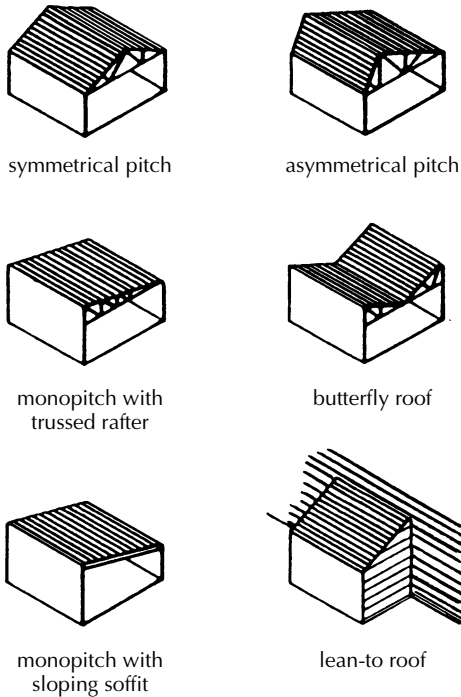
Figure 6.1   Slopping roofs.

system of struts. The strength and stability of this form of roof depends on
the depth of the triangular frames at mid-span. There is an inherent instability
across the slopes of this roof, parallel to the ridge, to the extent that wind
pressure may cause the frames to rack or fall over. To resist racking the frames
are braced by gable end walls, hipped ends or by cross-bracing (diagonal roof
boarding or braces fixed across sloping rafters). Typical forms of pitched roofs
are illustrated in Figure 6.1.

Resistance to weather

A roof prevents water entering a building by using a roof covering which
prevents rain penetration. The materials that cover the roof range from the
continuous impermeable layer of asphalt that can be laid horizontal to exclude
rain, to the small units of clay or concrete tiles that are laid overlapping or
interlocking so that rain runs off the roof to rainwater gutters.

When using small units to cover roofs, such as clay tiles, the tiles must have
considerable overlap and the slope of the roof should be laid at a greater pitch to
prevent the rain penetrating between the joints. Larger units such as profiled
metal sheets (see *Barry's Advanced Construction of Buildings*) can be laid at a
lower pitch than that required for tiles. Impermeable materials such as asphalt

and bitumen that are laid without joints can be laid flat and sheet metals such as lead and copper that are overlapped or joined with welts can be laid with a very shallow fall. The small open jointed units of tile and slate which provide little resistance to the penetration of wind into the roof require a continuous layer of felt or paper to exclude wind (often called sarking felt).

A roof structure will be subject to movements due to variations in loading by wind pressure or suction, snow loads and movements due to temperature and moisture changes. The great advantage of the traditional roofing materials, such as slate and tile, is that as the small units are hung, overlapping down the slope of roofs, the joints between the tiles or slates can accommodate movements in the roof structure without breaking slates or tiles or letting in rainwater. However, where the roof is covered with large unit size materials or continuous roof coverings they may fail (cracking and allowing rain penetration) if there is inadequate provision of movement joints.

Durability and freedom from maintenance
The durability of a roof depends on the ability of the roof covering to exclude rain, snow and the destructive action of frost and temperature fluctuations. Persistent penetration of water into the roof structure may cause or encourage decay of timber, corrosion of steel or disintegration of concrete. Pitched roof coverings are relatively durable and need little in the way of maintenance. In comparison most flat roof coverings by their nature have a shorter service life. With the introduction of more exacting requirements for the conservation of energy and increased insulation, combined with issues concerning durability of the roof covering the flat roof form has lost favour to the extent that many flat roofs have been rebuilt as pitched roofs to minimise repair and replacement costs.

Fire safety
The requirements for fire safety in the Building Regulations are concerned for the safe escape of occupants to the outside of buildings. The regulations require adequate means of escape, and limitation to internal and external fire spread. On the assumption that the structure of a roof will ignite after the occupants have escaped there is no requirement for resistance to fire of most roofs. However, the requirements do limit the external spread of fire across the surface of some roof coverings to adjacent buildings by limits to the proximity of buildings.

Resistance to the passage of heat
The materials of roof structures and roof coverings are generally poor insulators against the transfer of heat so it is necessary to use insulating materials to control excessive loss or gain of heat. The requirement of the Building Regulations for the insulation of roofs of dwellings is a maximum U value of $0.20\,\text{W}/\text{m}^2\,\text{K}$ for pitched roofs with insulation between rafters, $0.16\,\text{W}/\text{m}^2\,\text{K}$ with insulation

0.16 W/m²K for pitched roofs with insulation between joists

2.0 W/m²K for wooden or PVC framed roof lights (windows)
2.2 W/m²K for metal framed roof lights

loft

0.20 W/m²K for pitched roofs with insulation between rafters

0.25 W/m²K for flat roof with integral insulation

Heated
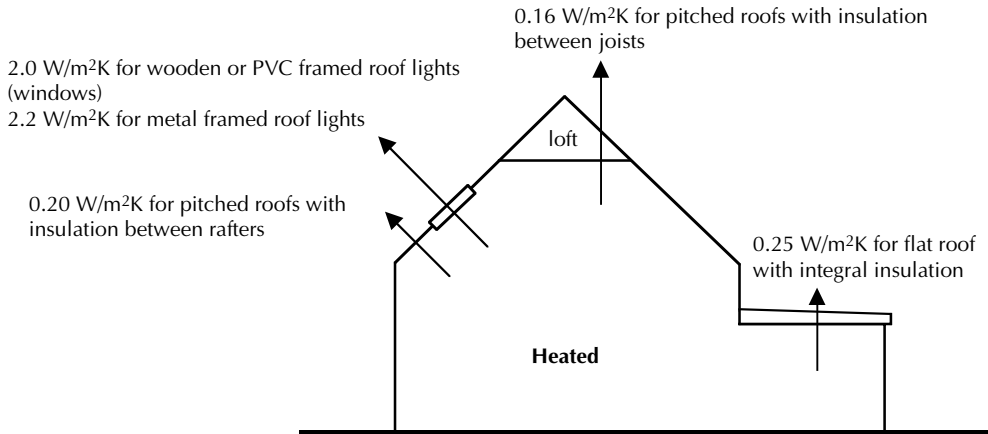
Figure 6.2   Standard U-values for roofs.

between joists, and 0.25 W/m² K for flat roofs of roof with integral insulation (Figure 6.2).

The most economical method of insulating a pitched roof is to lay or fix some insulating material between or across the ceiling joists, the area of which is less than that of the roof slope or slopes. This insulating layer will reduce the loss of heat from the building to the roof space, and reduce gain of heat from the roof space to the building. As the roof space is not insulated against loss or gain of heat it is necessary to insulate water storage cisterns and pipes in the roof against possible damage by frost, since the air space will be a similar temperature to that outside the building. This is termed a 'cold roof' type of construction (Figure 6.3A) and it is necessary to ventilate the roof space to prevent condensation in the cold air space.

Where the space inside a pitched roof is used for storage or as part of the building it is usual to insulate the underside of the roof slope. With the insulation fixed across the roof rafters, under the roof covering, the roof is insulated against changes in outside air temperature and is a form of 'warm' construction or a 'warm roof' (Figure 6.3B). The warm and cold roof terminology is also used for flat roof construction and is described in more detail later in this chapter.

Resistance to the passage of sound
The resistance of a roof to the penetration of airborne sound is not generally considered unless the building is close to an airport or busy road or rail network. The mass of the materials of a roof is the main consideration in the reduction of airborne sound. A solid concrete roof will have a greater effect in reducing airborne sound than a similar timber roof. The introduction of mineral fibre slabs, batts or boards to a timber roof will have some effect in reducing intrusive, airborne sound.

A **insulation fitted above ceiling – cold roof**   B **insulation installed along the slope – warm roof**
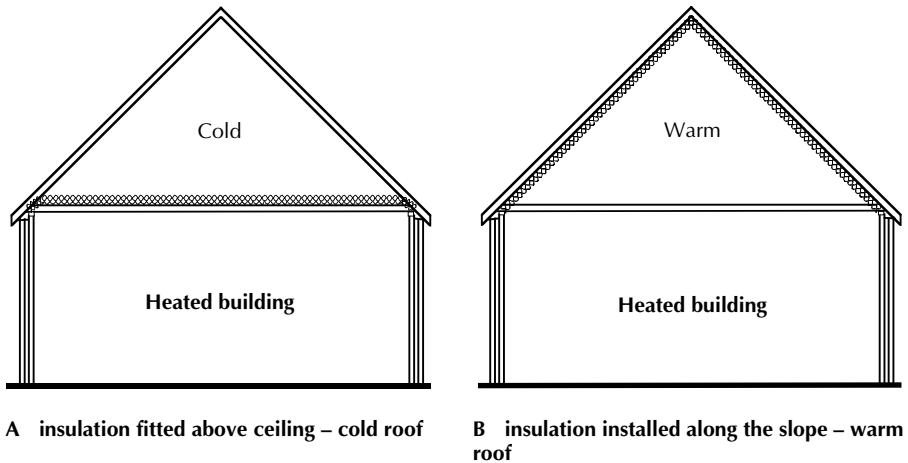
Figure 6.3   Cold and warm pitched roof construction.

6.2 Pitched roofs

The majority of pitched roofs are constructed as symmetrical pitch roofs with equal slopes pitched to a central ridge. The least slope of a pitched roof is determined by the minimum slope necessary for the roof covering to exclude rain and snow. The traditional pitched roof is constructed with slopes pitched at least $20°$ to the horizontal for tiles and $40°$ to $60°$ for slates.

Terminology

The terms used to describe the parts of a pitched roof are illustrated in Figure 6.4. The ridge is the highest, usually central horizontal part of a pitched roof. Eaves is a general term used to describe the lowest part of a slope from which rainwater drains to a gutter or to the ground. A gable end is the triangular part of a wall that is built up to the underside of roof slopes, and the junction of slopes at right angles to a wall, the verge. A valley is the intersection

Figure 6.4   Pitched roof.

ridge board

ends of
rafters
shaped

common
rafters

wall plate

3.5 m maximum span

A

roof tends to spread and
overturn walls
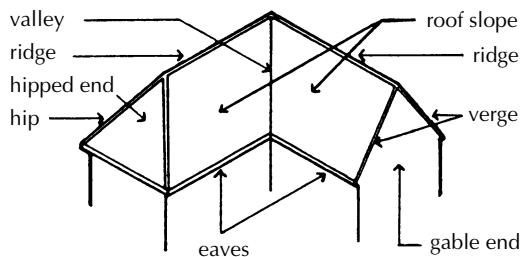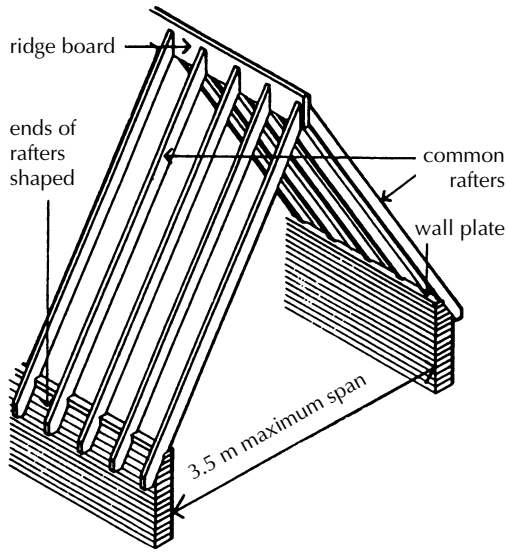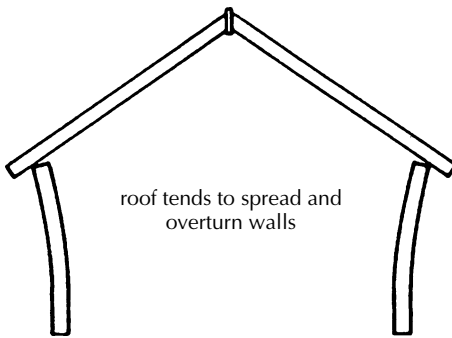
B

Figure 6.5   Couple roof.

of two slopes at right angles. A hipped end is formed by the intersection of two, generally similar, slopes at right angles.

Couple roof
The simplest form of pitched roof structure consists of timber rafters pitched up from supporting walls to a central ridge. This form of pitched roof is termed a couple roof as each pair of rafters acts like two arms pinned at the top, known as a 'couple' and illustrated in Figure 6.5A.

Pairs of rafters are nailed each side of a central ridge board. The lower part or foot of each rafter bears on, and is nailed to, a timber wall plate, which is fixed to the walls. When this form of roof is covered with slates or tiles and subject to wind pressure there is a positive tendency for the foot of the rafters to

spread and overturn the walls on which they bear, as illustrated in Figure 6.5B. Spreading of rafters is only weakly resisted by the nailed connection of rafters to ridge board, which does not act as an effective tie. The maximum span of this roof is generally limited to 3.5 m.

Couple roofs have been used to provide shelter for farm buildings and stores with the ends of such buildings formed with gable ends built in brick or stone or timber framed and rough boarded. The most straightforward way of providing a tie to resist the spread of the foot of rafters is to fix a metal or timber tie rod between the foot of pairs of rafters. By this device working spans of up to 5 m are practical.

Rafters are spaced from 400 to 600 mm apart to provide support for tiling or slating battens. Tiles are hung on and nailed to battens and slates nailed to battens. The necessary size of rafter depends in part on the spacing of rafters and mainly on the clear span, measured up the length of the rafter from the support on the wall plate to the ridge. Sawn softwood rafters for a typical couple roof would be 100 mm deep by 38 mm thick to provide reasonable support for the roof, its covering and wind and snow loads.

Ridge board

The purpose of the ridge board is to provide a means of fixing the top of pairs of rafters. A softwood board is fixed with its long axis vertical and its length horizontal. The top of rafters is cut on the splay so that pairs of rafters fit closely to opposite sides of the ridge board to which they are nailed, as illustrated in Figure 6.6.

The ridge board is one continuous length of softwood, usually 32 mm thick. The depth of the ridge board is determined by the depth of the splay cut ends

top of rafters cut and nailed either side of ridge

continuous ridge board
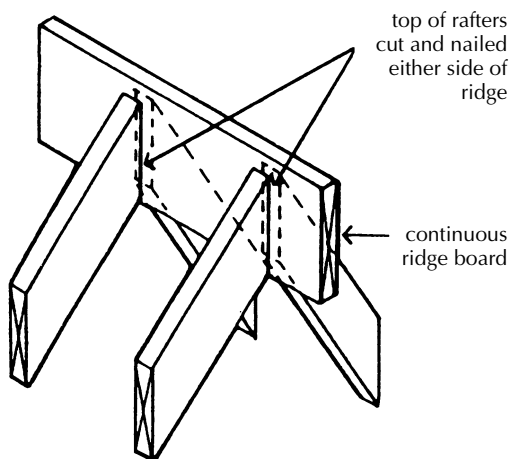
Figure 6.6   Ridge board.
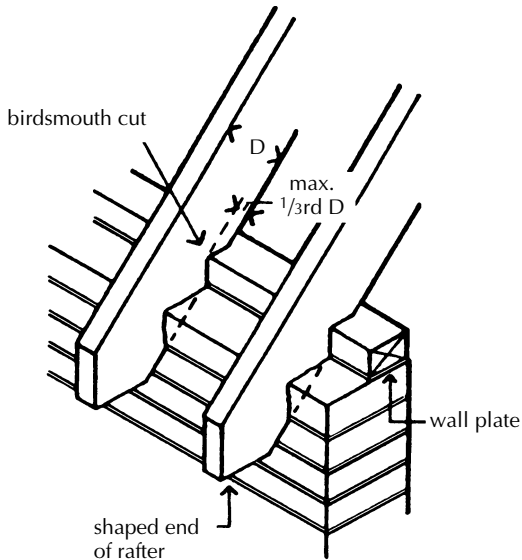
Figure 6.7   Wall plate.

of rafters that must bear fully each side of the board. A steeply pitched roof and deep rafters will need a deeper ridge board than a shallow pitched roof. The ridge board is usually some 50 mm deeper than required as bearing for rafter ends, to provide fixing for battens.

Wall plate

A continuous timber wall plate is fixed on walls by steel brackets. The wall plate provides a means of support and fixing for the foot of rafters to the wall. The sawn softwood plate, usually 100 × 75 mm in section, which is laid on its 100 mm face, serves to spread the load from rafters along the length of the wall.

A 'birdsmouth' cut is made in the top of each rafter to fit closely round the wall plate, as illustrated in Figure 6.7. Rafters are nailed to the wall plate. The birdsmouth cut should not be greater than one-third of the depth of a rafter. This limits the loss of strength in rafters so that the part of the rafter that projects over the face of the wall is still structurally sound; this projection is termed the eaves. The bearing of the rafter ends on the wall plate does not effectively resist the tendency of a couple roof to spread under load, to the extent that the plate may be moved by the spreading action of the roof.

Close couple roof

Pitched roofs to small buildings such as houses and bungalows are framed with rafters pitched to a central ridge board with horizontal ceiling joists nailed to the side of the foot of each pair of rafters, as illustrated in Figure 6.8. The ceiling
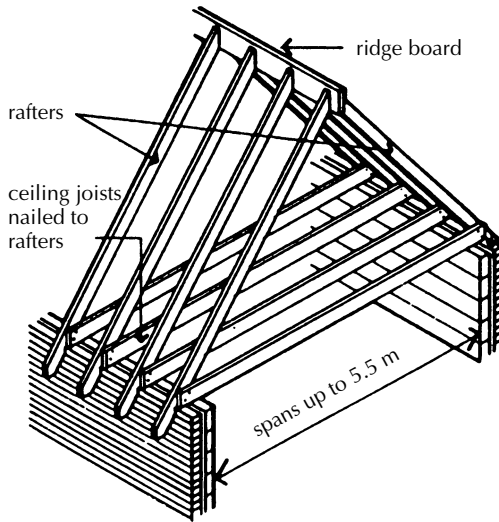
Figure 6.8   Close couple roof.

joists serve the dual purpose of ties to resist the natural tendency of rafters to spread and as support for ceiling finishes. Because the ceiling joists act as ties to the couple of pairs of rafters, this form of roof construction is a close couple or closed couple roof.

Ceiling joists are usually 38 or 50 mm thick and 97 to 220 mm deep sawn softwood, the size of the joists depending on the spacing and clear span between supports. The maximum span between supporting walls for the close couple roof illustrated is 5.5 m. For this span, ceiling joists with no intermediate support from internal walls would be 220 mm deep by 50 mm thick to support ceiling finishes without undue deflection.

The advantage of the triangular space inside the roof above the ceiling joists is that it will to some extent provide insulation, provide a convenient space for water storage cisterns and provide the storage space that is lacking in most modern house designs. The disadvantage of the close couple roof structure by itself is that the considerable clear spans of rafters and ceiling joists require substantial timbers as compared with similar roofs where there is intermediate support to rafters from purlins and to ceiling joists from binders.

Collar roof
Another form of tied couple roof is framed with collars joined across pairs of rafters, at most one-third up the height of the roof, as illustrated in Figure 6.9. The purpose of this arrangement is to extend first floor rooms into the roof space and so limit the largely unused roof space. A disadvantage of this arrangement is that the head of windows formed in a wall will be some distance below the ceiling and give less penetration of light. To provide normal height windows
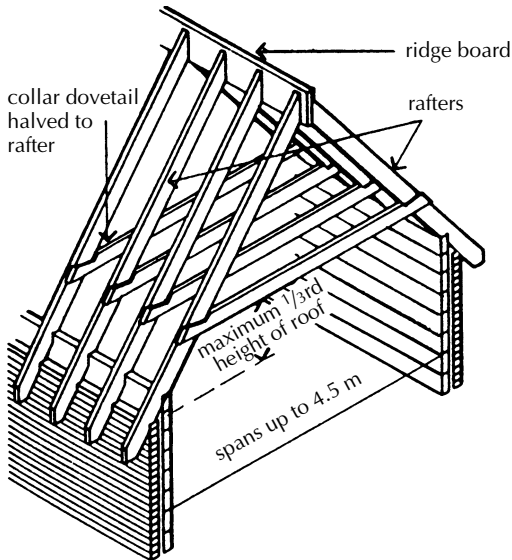
Figure 6.9   Collar roof.

a form of half dormer window is often used with the window partly built into the wall and partly as a dormer window in the roof.

A collar, fixed at up to a third up the height of a roof, is not as effective in tying the pairs of rafters together as standard ties at the foot of rafters. To provide a secure joint between the ends of collars and rafters, a dovetail half depth joint is formed. The ends of collars are cut to half their width in the shape of a half dovetail to fit into a similar half depth housing in rafters and the two nailed together, as illustrated in Figure 6.9. Because a collar is a less effective tie than a ceiling joist the maximum span of this roof is limited to 4.5 m. To provide solid framing the rafters are usually 125 × 44 mm and the collars 125 × 44 mm.

Purlin or double roofs

To economise in the section of roof rafters it has been practice to provide in-termediate support up the slope of roofs by the use of purlins. Purlins are horizontal timbers supported by end walls or struts to internal loadbearing walls. By the use of a comparatively substantial timber purlin an appreciable saving in timber rafter size can be effected because the clear span of the rafter is halved. Timber purlins are supported on masonry corbels built to project from separating walls or on metal joist hangers fixed into walls.

The roof illustrated in Figure 6.10 is framed with purlins for support for rafters and an internal loadbearing wall to provide intermediate support for ceiling joists to economise in timber sizes. The purlins illustrated are
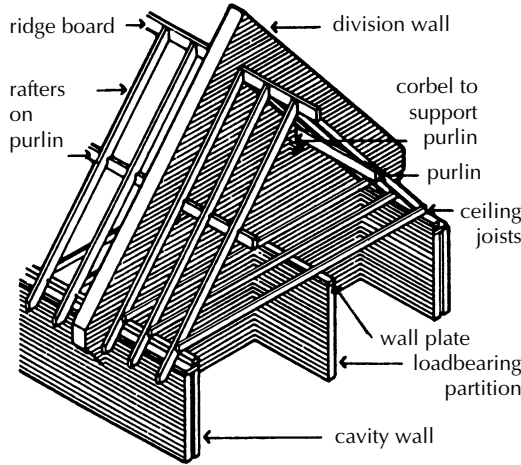
Figure 6.10   Purlin roof.

175×75 mm, the rafters 125×50 mm and the ceiling joists 125×50 mm sawn softwood.

Where there are no separating or gable end walls to provide support for purlins, an internal loadbearing wall can be used to support timber struts fixed between the wall and rafters, as illustrated in Figure 6.11.
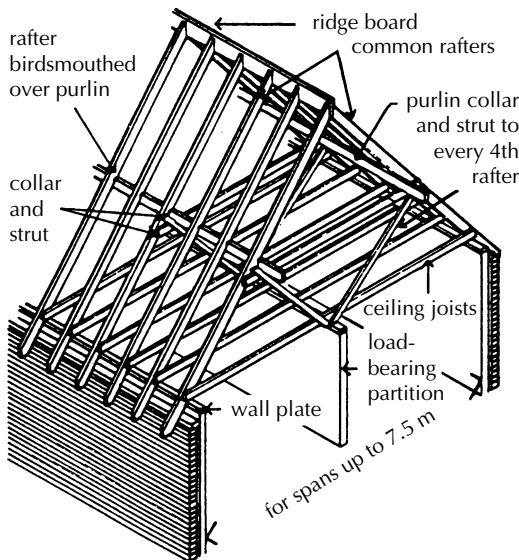
Figure 6.11   Double roof.

The purlins are fixed with their long axis vertical with rafters notched over and nailed to purlins. Horizontal collars are nailed to the side of every fourth pair of rafters under purlins. Pairs of struts are notched around a wall plate bedded on the internal wall, notched under and around purlins and nailed to the side of collars. Ceiling joists nailed to the foot of rafters and bearing on the internal wall serve as ties to the close couple roof and as ceiling support. Struts 75×75 mm support 150×50 mm purlins with 125×50 mm collars, 150×50 mm rafters and 125×50 mm sawn softwood ceiling joists.

Hipped ends of roof

To limit the expanse of roof to detached buildings such as houses, for appearance sake, the ends of a pitched roof are sometimes formed as slopes described as hipped ends. The hipped, sloping ends of pitched roofs are usually framed at the same slope as the main roof. To provide fixing and support for the short length of rafters, which are pitched up to the intersection of roofs, a hip rafter is used as illustrated in Figure 6.12. To provide adequate bearing for the splay cut ends of rafters pitched up to it, the hip rafter is usually 200 to 250 mm deep and 38 mm thick. The short lengths of rafter pitched to the hip rafter are the same size as the rafters of the main roof. These shorter lengths of rafter, commonly
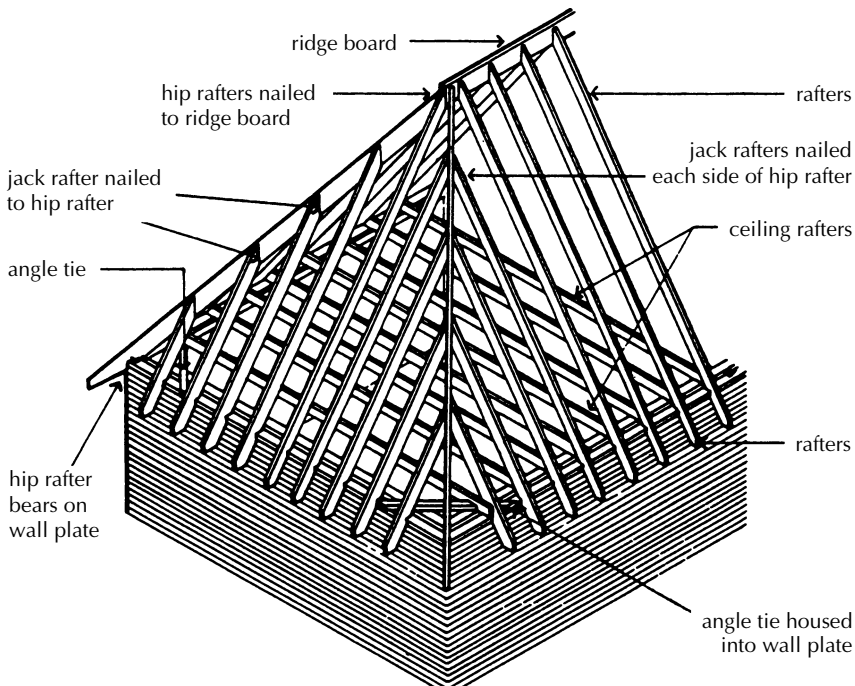
Figure 6.12   Hipped end.

termed 'jack rafters', are nailed to the hip rafter, and finished with shaped ends for gutter and soffit boards.

A hip rafter provides bearing and support for the ends of jack rafters, which support the roof covering and wind and snow loads. Because of the considerable load that a hip rafter carries it will tend to spread and displace the junctions of the wall plates on which it bears and overturn the walls that support it. To maintain the right-angle junction of wall plates and wall against the spread of a hip rafter it is necessary to form a tie across the right-angle junction. Angle ties are cut from 100×75 mm sawn softwood timbers. These ties are either bolted to the wall plate or dovetail housed into the wall plates some 600 mm from the angle across which they are fixed, as illustrated in Figure 6.12.

An advantage of a hip end roof is that the hip end acts to provide stability to the main roof against the tendency of a pitched roof to rack and overturn parallel to its ridge. The disadvantage of a hip end roof is the very considerable extra cost in the wasteful cutting of timber and roof covering at the hips. The hip end illustrated in Figure 6.12 is shown as a close couple roof. More usually this form of roof is framed as a purlin or double roof.

Valleys

The valley formed at the internal angle junction of two pitched roofs is framed in much the same way, in reverse, as a hip end. A valley rafter is pitched up from the junction of the wall plates at the internal angle junction of walls to the intersection of ridge boards, splay end cut to fit to the ridge and notched and housed over the wall plate and nailed in position. The 38 or 50 mm thick valley rafter is of the depth required to provide a bearing for the full depth of the splay cut ends of the rafters it supports and finish level with the tops of these rafters. The cut, jack rafters are nailed to the side of the ridge board and valley rafter respectively. The valley rafter is fixed in position with its top edge level with adjoining rafters so that it does not obstruct the battens that run down into the valley that will provide the structure for the valley gutter.

Trussed roof construction

A traditional method of constructing pitched roofs, with spans adequate to the width of most buildings, that do not need intermediate support from internal partitions was to form timber trusses. The word truss means tied together and a timber roof truss is a triangular frame of timbers securely tied together. The traditional timber roof truss was constructed with large section timbers that were cut and jointed with conventional mortice and tenon joints that were strapped with iron straps screwed or bolted to the truss. The traditional large section timber king post and queen post trusses supporting timber purlins and rafters were designed to be used without intermediate support, over barns, halls and other comparatively wide span buildings. The combination of the shortage of timber that followed the end of the Second World War (1945) and the need for greater freedom in planning internal partitions prompted the development of
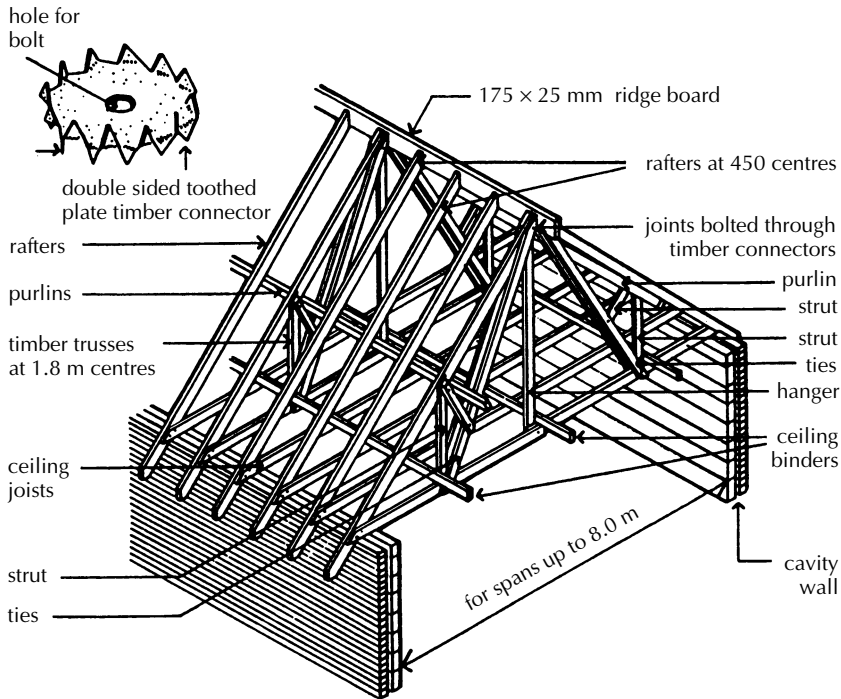
Figure 6.13   Trussed roof.

an economical timber truss designed by the Timber Development Association. The timbers of the truss were bolted together with galvanised iron timber connectors, illustrated in Figure 6.13, bolted between timbers at connections. The strength of the truss was mainly in the rigidity of the connection.

These timber trusses were designed for spans up to 8 m. Each truss was framed with timbers of the same section as the rafters and ceiling joists, which provided intermediate support too, through the purlins and binders they supported. The prefabricated timber trusses were fixed in position at 1.8 m centres bearing on and nailed to wall plates. The 175 × 25 mm ridge board was fixed and nailed to trusses. Purlins, 150 × 50 mm, were placed in position supported by struts and nailed to struts and rafters. Ceiling binders 125 mm deep by 50 mm wide were placed in position on 100 × 38 mm ceiling joists. To complete the roof framing, 100 × 38 mm rafters were cut to bear on the ridge board, notched over purlins and wall plate, and then nailed in position. Ceiling joists were nailed to the foot of rafters and the underside of ceiling binders.

The advantage of this trussed roof construction is that the continuity of the ridge board, purlins and binders along the length of the roof together with roofing battens provided adequate stability against racking. Trussed roof

construction has been largely replaced by pre-fabricated trussed rafter roofs that require somewhat less timber and less skilled labour.

Pre-fabricated trussed rafters

For the maximum economy in site labour and timber the trussed rafter roof form was first used in the UK in the 1960s and has since been used extensively for housing and smaller commercial developments. Trussed rafters are fabricated from light section, stress graded timbers that are accurately cut to shape, assembled and joined with galvanised steel connector plates. Much of the preparation and fabrication of these trussed rafters is mechanised, resulting in accurately cut and finished rafters that are delivered to site ready to be lifted and fixed as a roof frame with the minimum of site labour.

The members of the truss are joined with steel connector plates with protruding teeth that are pressed into timbers at connections to make a rigid joint. Trussed rafters, that serve as rafters and ceiling joists, are fixed at from 400 to 600 mm centres, as illustrated in Figure 6.14 for spans up to 12 m for roofs pitched at 15° to 40°. The trussed rafters bear on and are nailed to wall plates. As the rafters are trussed there is no need for a ridge board to provide a bearing and fixing for rafters.

Approved Document A states that, for stability, trussed rafter roofs should be braced to the recommendations in BS 5268: Part 3. For the roofs of domestic buildings the members of trussed rafters with spans up to 11 m should be not be less than 35 mm thick and those with spans of up to 15 m, 47 mm thick. These slender section trusses are liable to damage in storage and handling. They should be stored on site either horizontal on a firm level base or in a vertical

tiling battens 19 × 38 mm
for rafters at 400 mm
centres and 25 × 38 mm
for 540 and 600 mm

galvanised steel gang-nail
connector plates

trussed rafters at 400, 450
or 600 mm centres

rafters on wall plate
on cavity wall
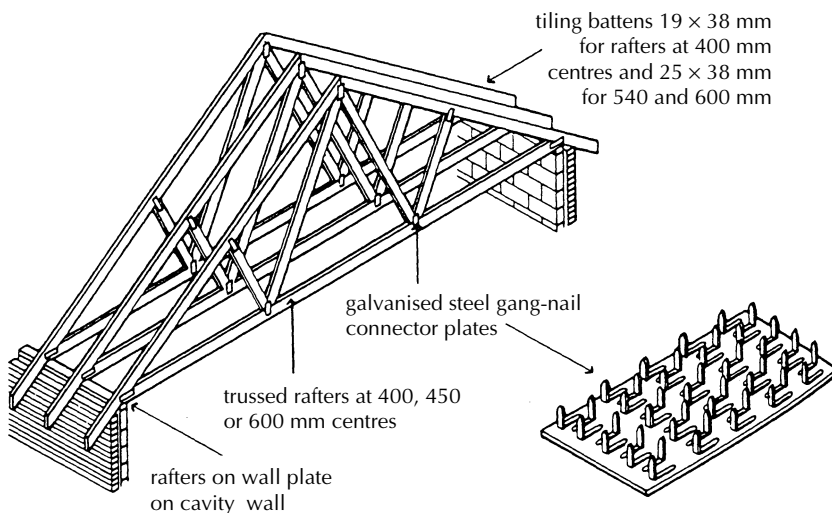
Figure 6.14   Trussed rafter roof.
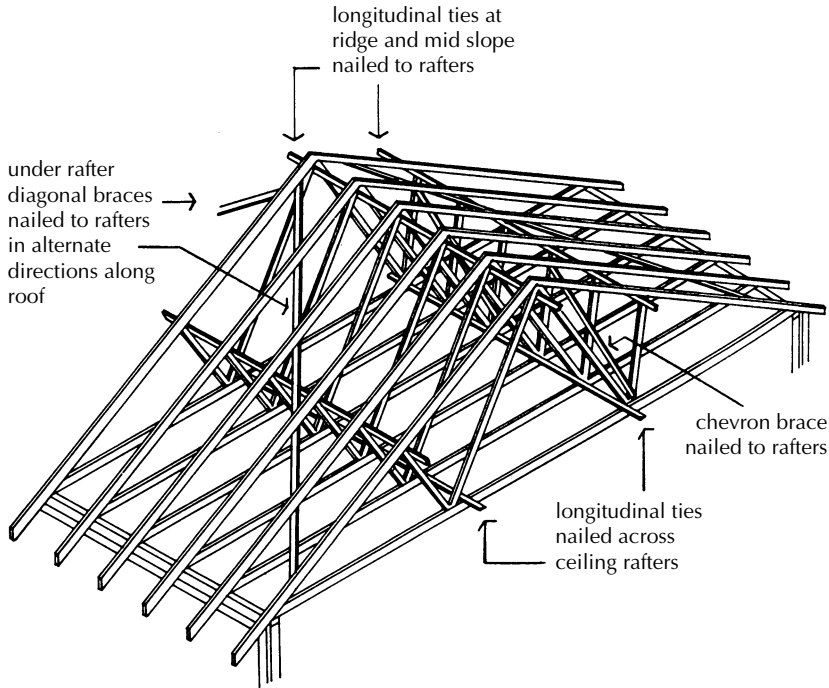
Figure 6.15   Stability bracing to trussed rafters.

position with adequate props to avoid distortion. In handling into position each truss should be supported at eaves rather than mid-span to avoid distortion. The trussed rafters should be fixed vertical on level wall plates at regular centres and maintained in position with temporary longitudinal battens and raking braces. The rafters should be fixed to wall plates with galvanised steel truss clips that are nailed to the sides of trusses and wall plates. A system of stability bracing should then be permanently nailed to the trussed rafters. The bracing that is designed to maintain the rafters in position and to reduce buckling under load is illustrated in Figure 6.15. The bracing members should be $25 \times 100\,mm$ and nailed with two $3.35 \times 75\,mm$ galvanised, round wire nails at each cross-over. The longitudinal brace at the apex of trusses acts in much the same way as a ridge board and those halfway down slopes act like purlins to maintain the vertical stability of trusses. The longitudinal braces, also termed binders, at ceiling level serve to resist buckling of individual trussed rafters. The diagonal under rafter braces and the diagonal web braces serve to stiffen the whole roof system of trussed rafters by acting as deep timber girders in the roof slopes and in the webs. Manufacturers of roof trusses provide the design and layout of the prefabricated trusses and structural calculations as part of the overall service offered to designers and contractors.

A Gang nail plate holds members of the truss in position

B Cavity sock seals the top of the cavity at gable end

C Diagonal bracing across roof trusses

D Forming valley at intersection of roofs

Photograph 6.1   Truss roof construction.

Eaves

Eaves is a general term used to describe the lowest courses of slates or tiles and the timber supporting them. The eaves of most pitched roofs are made to project some 150 to 300 mm beyond the external face of walls. In this way the roof provides the top of the wall with some protection from rain (Figure 6.16A). 'Closed' or 'flush' eaves provide little protection to the wall, but are used to economise in timber and roof covering (Figure 6.16B). The ends of the rafters and ceiling joists are cut flush with the outside face of the wall below. A fascia or gutter board 25 mm thick is nailed to rafters and ceiling joist ends.

The necessary depth of the gutter board is such that it covers the cut ends of rafters and projects some 25 to 30 mm above the top of rafters to act as a bearing for the lowest courses of tiles or slates which project over it some 25 mm to discharge rainwater into a gutter fixed to the gutter board (Figure 6.16C).
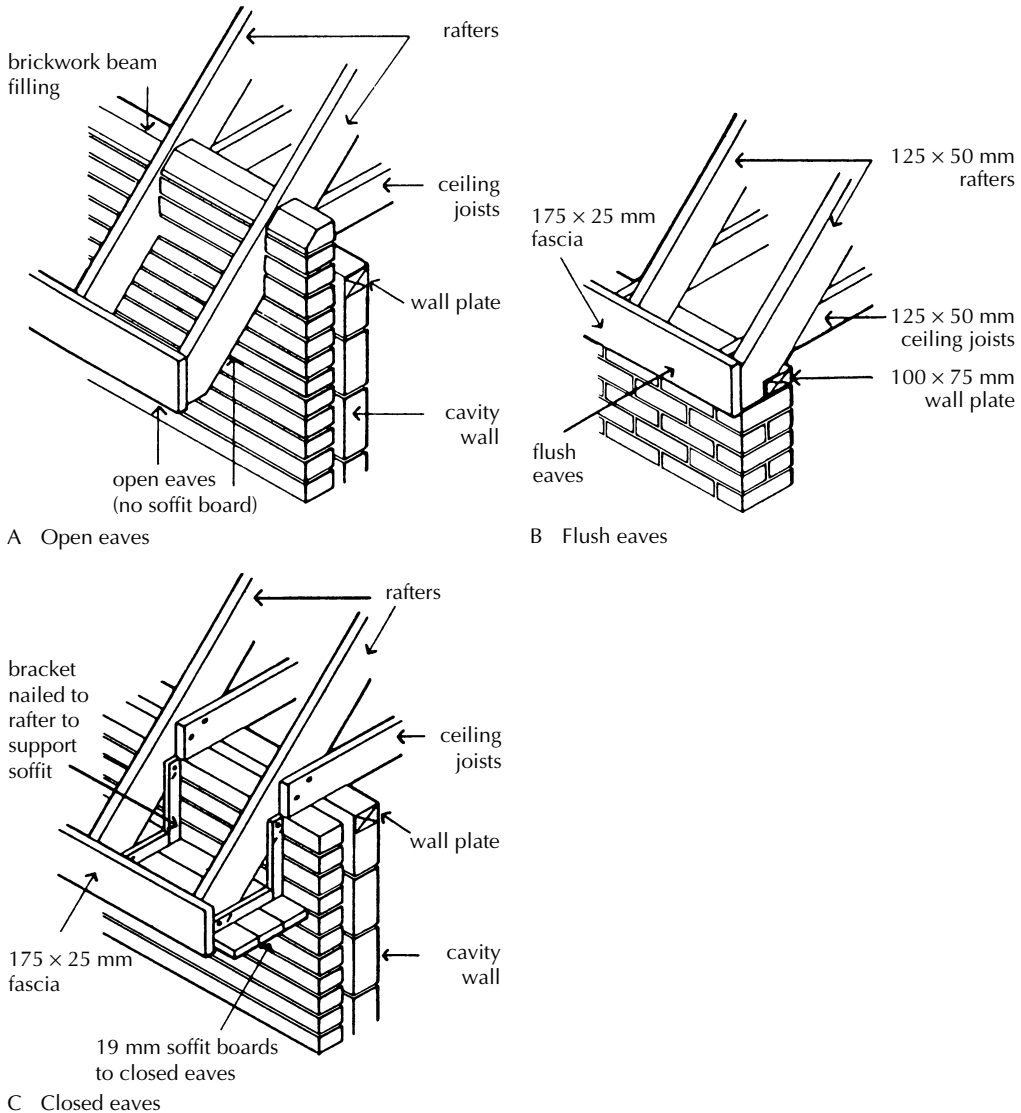
Figure 6.16   (A) Open eaves. (B) Flush eaves. (C) Closed eaves.

Insulation is not shown in the previous figure allowing various components to be seen. Figure 6.17 shows the general arrangement of insulation and ventilation components at the eaves.

To prevent the build up of stagnant air and condensation forming, ventilation is required. This is normally provided by ventilation gaps at the eaves and the ridge of the roof structure. The Building Regulations require that the ventilation gap varies with the pitch of the roof. If there is a ventilation gap of minimum

Single lap interlocking tiles

Timber tile battens

Plastic cross flow ventilator ensures 25 mm (min) air gap to roof space

Sarking (or breathable roofing membrane) turned into gutter

Cavity fully sealed with calcium silicate board or full insulation (mineral wool)

Fascia board

Soffit with disc or slot type ventilator allowing equivalent of 10 mm (min) ventilation continuous

Figure 6.17   Typical insulation and ventilation requirements at eaves.

25 mm along the length of the eaves any pitch can be used. If the roof is greater than 35° pitch, 10 mm ventilation is sufficient (Figure 6.17). Where the attic is converted into a room, then 25 mm ventilation at the eaves is required.

Dormer windows

Dormer windows are framed as a vertical window, whereas roof lights are formed as a glazed opening in the slope of the roof. Dormer windows may be framed as a projection from the roof slope, recessed behind the slope or partly projecting from the roof and partly in the face of the wall below, as illustrated in Figure 6.18.

A recessed dormer window is particularly suited to a Mansard form of roof. To provide the maximum number of floors it is often practice to form one or several floors inside a roof sloping at 60° with recessed dormer windows to provide daylight. The advantage of the Mansard slope form of pitched roof,

projecting

recessed

partly
projecting
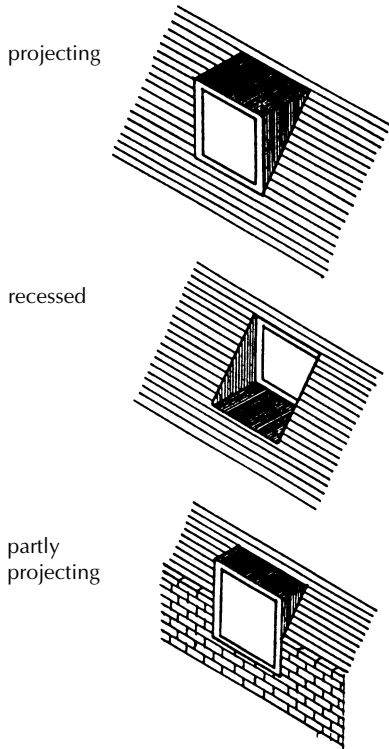
Figure 6.18   Dormer windows.

illustrated in Figure 6.19, is that it provides maximum useful floor area. Where
there are no restricting angles of light a Mansard roof space may be formed
with projecting dormer windows.

The opening in roof rafters for dormer windows is framed between trimming
rafters and the head and cill trimmers, which provide support for the trimmed
rafters, as illustrated in Figure 6.20. The roof and cheeks of the dormer are
boarded for lead, copper sheet or vertically hung tiles. The junction of the
main roof covering with the sheet metal covering of the roof and cheeks of the
dormer is weathered with lead or copper flashings and gutter.
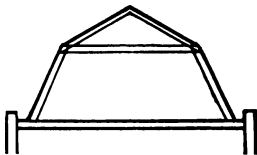
Figure 6.19   Mansard roof.
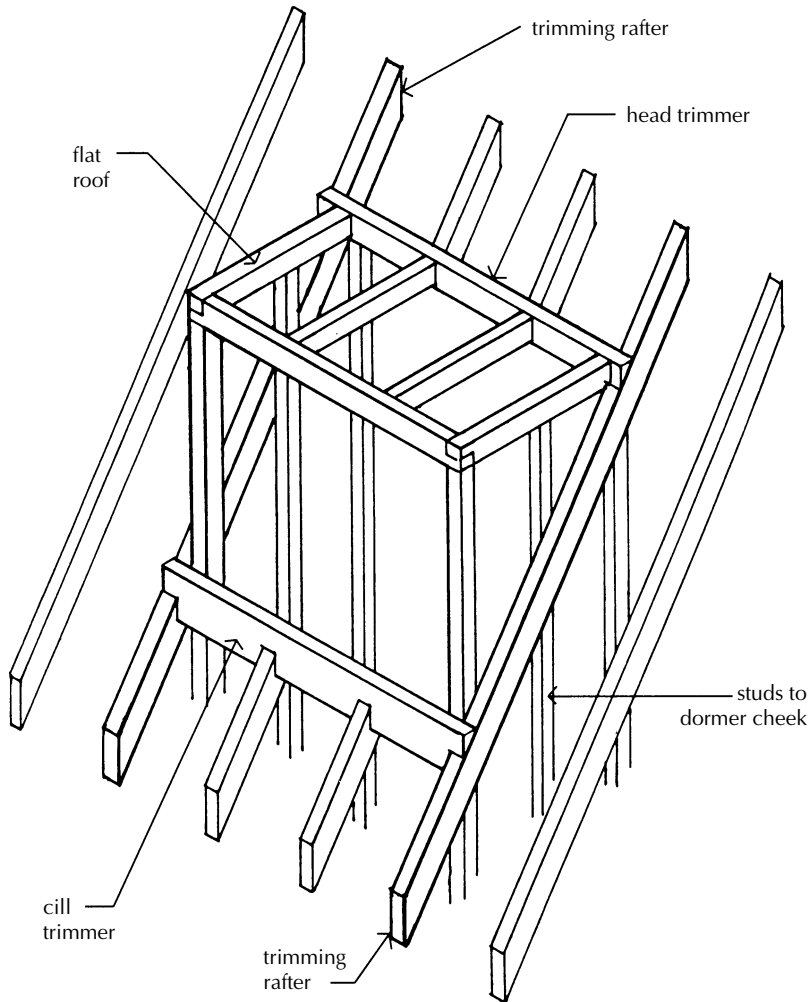
Figure 6.20   Dormer windows framing.

Roof light

Prefabricated roof lights are available that help to facilitate the rapid construction of a roof. Roof lights (such as Velux windows) are simply fitted between the roof joists as shown in Figure 6.21. See also Photograph 6.2.

Fire safety

The space inside a pitched roof is a void space that should be separated from other void spaces or cavities by cavity barriers, sealing the junction of the cavity and preventing spread of smoke and flames. The cavity in a wall is generally separated from the cavity in a pitched roof by the cavity barrier at the top of

Interlocking tiles

Tile battens
Flashing

Tilting roof light

Support bracket

Flashing

Lead apron

Trimmer joists between raft

Breathable vapour barrier

Counter battens

Roof light
(velux)

Room
space
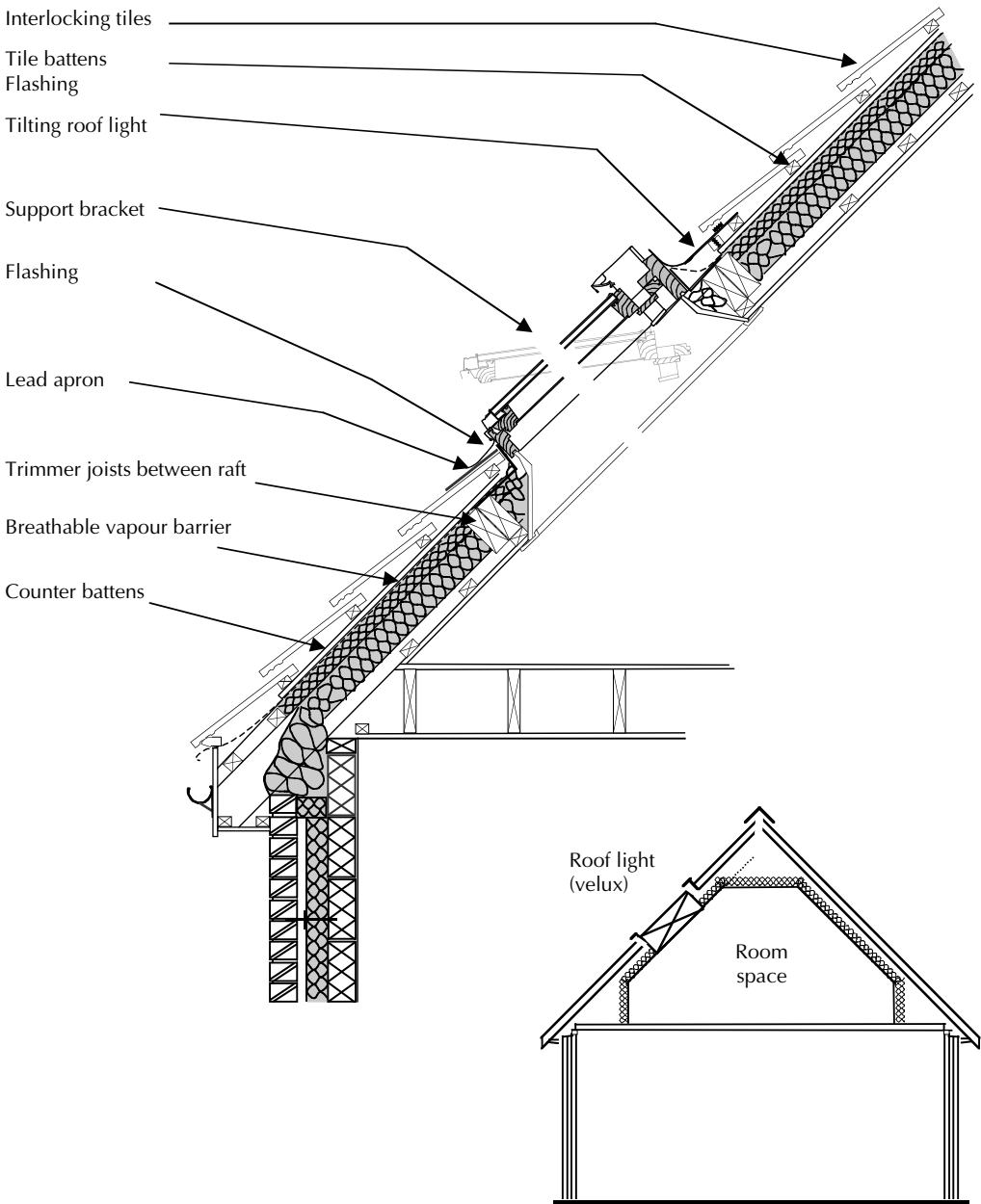
Figure 6.21   Roof light.

Photograph 6.2   Rooflight (Velux).

the cavity in the wall. Cavities in walls should also be sealed to improve air tightness and increase thermal properties (still air is a good insulator).

Separating walls, party walls, between semi-detached and terraced houses should resist the spread of fire from one house to another by being raised above the level of the roof covering or by being built up to the underside of the roof covering so that there is a continuous fire break. Other patented systems of fire barriers are available for industrial and commercial buildings. The traditional roof coverings, slate, tile and non-ferrous sheet metal, do not encourage spread of flame across their surface and are, therefore, not limited in use in relation to spread of fire between adjacent buildings.

6.3 Pitched roof coverings

The traditional covering for pitched roofs in England and northern European countries has been clay tile and natural slate. These traditional roof coverings are still extensively used for new houses and other small buildings for their appearance, durability and freedom from maintenance. Sustainable materials, such as thatch, have started to be used again.

Thatch

This is a traditional building material that is rarely used in modern develop-ments. Long straight stalks of reeds are cut, dried, bound together and laid up
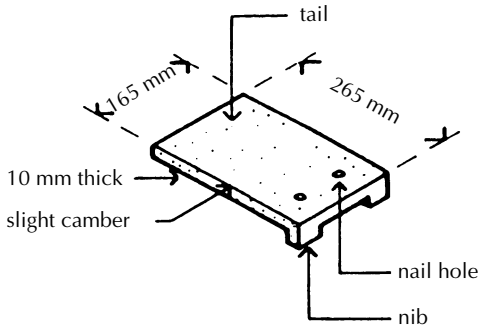
Figure 6.22   Plain tile.

the slopes of pitched (sloping) roofs as thatch. Thatch efficiently drains rainwater, excludes wind and acts as a very effective insulator against transfer of heat, a combination of advantages that no other roof covering offers. The disadvantage of thatch is that the dry material readily ignites and burns vigorously and the thick layer of thatch is an ideal home for small birds, rodents and insects. Fire protection is required to the underside of the thatched roof to comply with regulations and building insurance policies. The durability of thatch will depend on the material used and the skills of the thatcher; replacement should be expected every 20 to 30 years.

Plain tiles

A plain tile is a rectangular roofing unit of burned clay. Plain tiles are made with a small upward camber, so that when laid overlapping, the tail of a tile bears directly on the back of a tile below. Early plain tiles were made with two holes for oak pegs on which the tiles were hung on battens. Plain tiles are now made with two nibs for hanging to battens, as illustrated in Figure 6.22. The two holes near the head of the tile are for nailing tiles to timber battens.

Plain tiles are hung on battens in overlapping horizontal courses with the side joints between tiles bonded up the roof so that rain runs down the slope from tile to tile to the eaves. There are at least two thicknesses of tile at any point on the roof and also a 65 mm overlap of the tail of each tile over the head of tiles two courses below. The reason for this extra overlap is that, were the tiles laid in a straightforward overlap, rain might penetrate the roof. If plain roof tiles were only lapped once, rain running off tile A in Figure 6.23 will run into the gap between tiles B and C, and spread over the back of tile D, as indicated by the hatching, and probably drip over the top of tiles E and F into the roof. To avoid this all tiles are double lapped.

Lap, gauge and margin
With a 65 mm double end lap, plain tiles are laid to overlap 100 mm up the roof slope. The softwood battens on which the tiles are hung must therefore
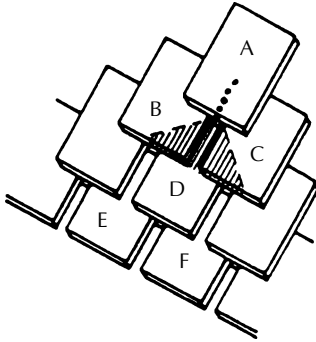
Figure 6.23   Rain flow over plain tiles.

be fixed at a gauge (measurement) of 100 mm centres. The tail end of each tile shows 100 mm of the length, which is described as the margin, as illustrated in Figure 6.24.

Minimum slope of roof

The minimum roof slope for plain tiles depends on the density of the burned tile. Hand made tiles, which fairly readily absorb water, should not be laid on a roof slope pitched at less than 45° and the more dense machine pressed tiles at not less than 35°. Because of the thickness and double lap of these tiles, the actual slope of a tile on a roof will be a few degrees less than that of the roof slope. Manufacturers provide comprehensive guidance for their own products.

Roofing felt (sarking and sarking felt)

The open butt, side joints of tiles and inexact fit of tile over tile would allow wind to blow into the roof space. To exclude wind it is practice to cover roof slopes with roofing sarking. Rolls of sheet sarking are laid across roof rafters from the eaves upward with widths of felt lapped 75 to 150 mm up to the ridge. Various materials are available, including breathable membranes, reinforced plastic and flexible felt material. Breathable membranes allow unwanted water vapour to escape from the roof space while still excluding wind. Ventilation through the roof and breathable membranes reduce the potential for condensation to form on the cold surfaces within the roof. Timber battens secure the sarking covering, as illustrated in Figure 6.24.

When it is planned to use a roof space for dry storage it is usual to cover roof slopes with either plain edge or tongued and grooved boarding laid across and nailed to rafters to prevent wind and dust entering. Counter battens are then fixed up the slopes, over roofing felt as illustrated in Figure 6.25. The roofing felt will then conduct any water that penetrates the tiles down to the eaves. The roof boarding, sometimes called sarking, acts to brace a pitched roof against its inherent instability across the slope of the roof.

tile and a half width tile in every other course to complete bond

265 × 165 mm plain tiles huge double lap with every fourth course nailed

black haired roofing felt fixed across rafters

40 × 20 mm battens at 100 mm gauge

verge

248

100 mm margin

rafter

lap 65

ceiling joists

100 × 75 mm wall plate

180

175 × 25 mm fascia

double course at eaves using 180 mm under eaves tiles

cavity wall

Figure 6.24   Plain tiling.

plain tiles

battens nailed to counter battens at 100 mm gauge

boards

roofing felt nailed across roof

rafter

Figure 6.25   Roof boarding and counter battens.

Tiling battens

Plain tiles are hung on 38 × 19 mm or 50 × 25 mm sawn softwood battens, which are nailed across rafters at 100 mm centres (gauge). As protection against the possibility of rain penetrating tiles and causing damage to battens by rot, the battens should be impregnated with a preservative. So that nails do not rust and perish they should be galvanised or made of a non-ferrous alloy. The tiles in every fourth course are nailed to battens as a precaution against high wind lifting and dislodging tiles. In exposed positions every tile should be nailed.

Eaves

So that there are two thicknesses of tile at the eaves a course of eaves tile is used. These special length tiles are 190 mm long so that when hung to battens their tails lie directly under the tail of the course of full tiles above, as illustrated in Figure 6.24. The tails of both the eaves tiles and full tiles above bear on the gutter board and project beyond the face of the board to discharge run-off water into the gutter.

At the ridge a top course of tiles is used to overlap the course of full length tiles below to maintain the necessary two thicknesses of tile. These top course tiles are 190 mm long and hung on 40 × 40 mm battens, which are thicker than normal battens, so that top course tiles ride over the tiles below. The ridge tiles are bedded on the back of the top course tiles so that the usual margin of tile is showing. The ends of the ridge tiles are solidly filled with mortar as a backing for the mortar pointing, as illustrated in Figure 6.26.

Figure 6.27 illustrates four different ridge tiles; which section is used depends in part on the slope of the roof and also on the desired appearance. In
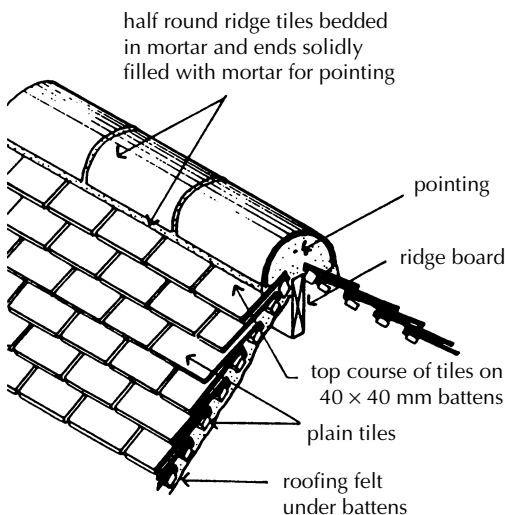
Figure 6.26   Ridge.
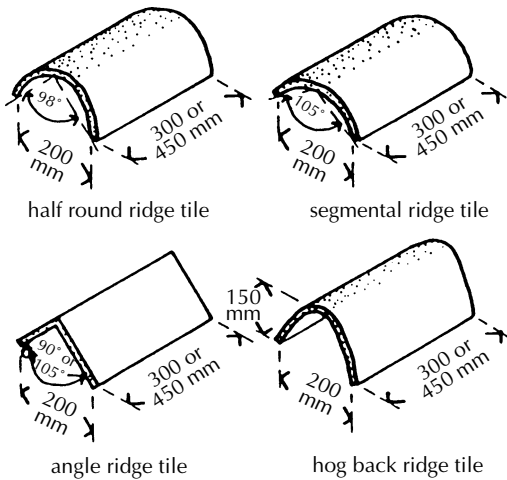
Figure 6.27   Ridge tiles.

addition to the ridge tiles illustrated, 'specials' can be produced for decorative purposes.

Verges
The bonding of tiles at verges of plain tile roofing at the junction of a roof with a gable end and the junction of square abutments of slopes to parapet walls is completed with tile and a half width tiles 248 mm wide in every other course. The use of tile and a half width tiles at the verge of a tiled roof and a gable end is illustrated in Figure 6.28. The verge tiling is hung to overhang the gable end

Figure 6.28   Verge.

angular hip tile   bonnet hip tile

Bonnet hip
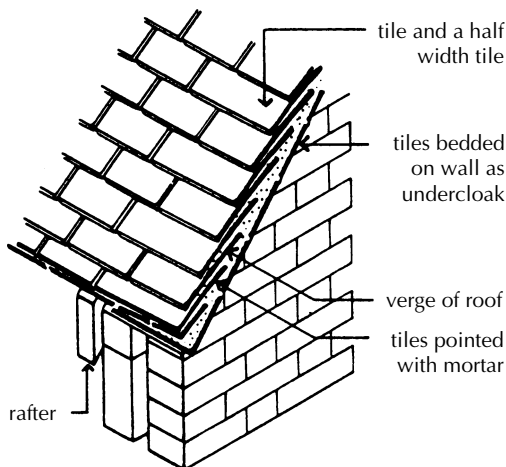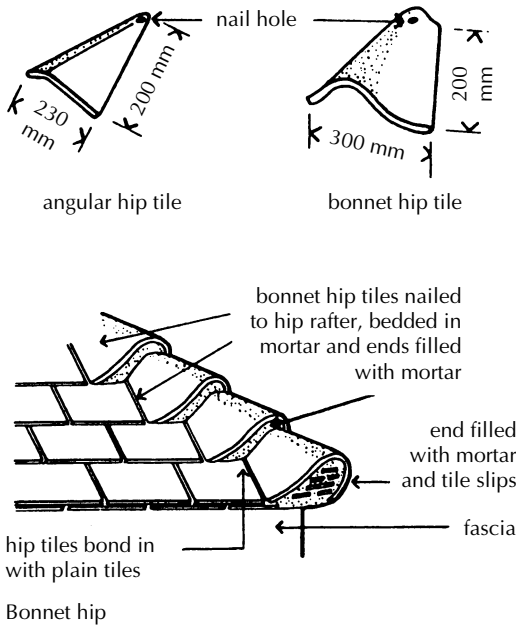
Figure 6.29   Hip tiles.

wall by some 25 mm and the tiles are tilted slightly towards the roof slope to encourage rain to run down the roof slope rather than down the gable end wall.

Hip ends

Hip tiles are manufactured to bond in with the courses of tile in the adjacent slopes to provide a more pleasing appearance to the roof. Two sections of hip tile are produced. The angular and the bonnet hip tile, illustrated in Figure 6.29, have holes for nailing the tiles to the hip rafter. The hip tiles are nailed to the hip rafter up the slope of the hip and overlap so that the tail of each tile courses in with a course of plain tiles. The hip tiles are bedded in mortar on the back of plain tiles which are cut to fit close to the hip and the end of hip tiles is filled with cement mortar as illustrated in Figure 6.29. For the sake of appearance the end hip tile is filled with mortar with slips of cut tile bedded in the mortar.

Valleys

At the junction of plain tile covered roof slopes in a valley, formed by an internal angle of walling, either a lead gutter is formed or special valley tiles are used. The valley is formed as a lead lined gutter dressed into a gutter formed by timber valley boards. The valley gutter should be wide enough to allow such
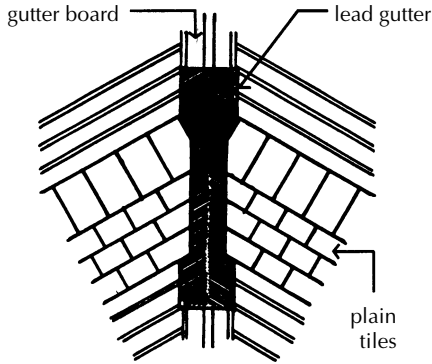
Figure 6.30   Lead valley gutter.

debris as dust and leaves to be washed down to eaves without being obstructed and so blocking the gutter. A clear width of at least 125 mm is usual.

Gutter boards 25 or 38 mm thick and some 200 mm wide are nailed to the top of rafters, each side of the valley, with a triangular fillet of wood in the bed of the gutter as illustrated in Figure 6.30. Tiling battens are continued down over the edges of the gutter boards. Roofing felt is laid under battens and over a double depth batten nailed at the cut ends of roofing battens.

As an alternative to a valley gutter, special valley tiles may be used to course in with the tile slopes each side of the valley. Some of the manufacturers of tiles provide valley tiles of the same material as their plain tiles. These valley tiles are shaped so that they bond in with tiles on main slopes pitched at specific angles. The length of the tile provides for the normal end lap. The dished tile tapers towards its tail, as illustrated in Figure 6.31. The valley tiles are nailed to tiling battens continued down to the valley with plain tiling hung to side butt to valley tiles using tile and a half width tiles as necessary.
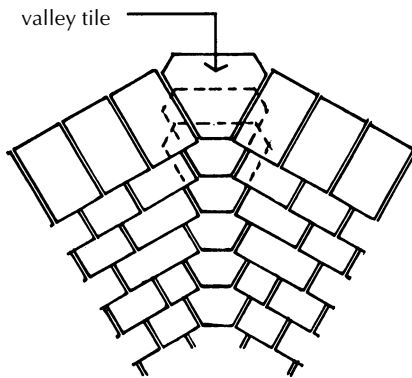
Figure 6.31   Valley tiles.

Concrete plain tiles

Concrete plain tiles are made from a mixture of carefully graded sand, cement and water, which is compressed in a mould. A thin top dressing of sand, cement and colouring matter is pressed into the top surface of the tile. The moulded tiles are then left under cover for some days to allow them to harden. Concrete tiles are uniform in shape, texture and colour, however concrete tiles are more normally made as interlocking units as described below.

Single lap tiles

Single lap tiling is so called because each tile is laid to end lap the tile below down the slope of a roof and to side lap over and under the tiles next to it, in every course of tiles. The two types of single lap tile that have, for very many centuries, been used throughout the world are the rounded unders (channel) and overs (cover) and the flat unders (channel) and round overs (cover) tiles illustrated in Figure 6.32. These traditional tiles are called Spanish and Italian tiles, respectively, even though they are not specific to those countries. In the UK these tiles have been replaced by pantiles in which the rounded unders and overs are combined as one pantile and the flat unders and rounded overs of Italian tiles are combined as single and double Roman tiles.

Pantiles

A pantile incorporating the rounded unders and overs of Spanish tiles in one tile is illustrated in Figure 6.33. By the use of selected clays or cement and sand and machine pressing this larger tile can be produced in standard sizes of uniform shape. The advantage of this tile is that it can be hung to be comparatively close fitting to exclude wind and rain. Both clay and concrete pantiles were fairly extensively used before the advent of interlocking tiles. Clay pantiles have been made with a fired on glazed finish to all exposed faces and edges, in a range of vivid colours, for the dramatic effect of this roof covering.

Pantiles are made with a nib for hanging on to battens and a nail hole for securing tiles by nailing to battens against wind uplift. The tiles are hung on to 50×20 mm sawn softwood battens, nailed to rafters over roofing felt. The tiles are hung with an end lap of 75 mm at a gauge of 270 mm. The purpose of the mitred corners of pantiles is to facilitate fixing. But for the mitred corners there would be four thicknesses of tile at the junction of horizontal and vertical joints, which would make it impossible to bed tiles properly.

Ridge tiles are bedded over the backs of pantiles and pointed at butt joints in cement and sand. As a bed for mortar filling, a course of plain tiles is hung at eaves on which mortar and tile slips are used to end fill pantiles. The pitch of roof for pantiles may be as low as $20°$ to $35°$, depending on exposure. An illustration of a roof covered with pantiles can be seen in Figure 6.33.

channel tile
(under)

cover tile
(over)

channel tile
(under)

cover tile
(over)

Spanish tiles

Italian tiles

ridge tiles lap 75 mm
over roof tiles

ridge tiles bedded
in mortar

ridge board

ridge tiles and
roof tiles filled
with tile slips
in mortar

end lap

channel
tiles

end lap
75 mm

75 × 50 mm
battens

boarding

felt

roof rafters

soffit board

fascia board

tile ends filled
with tile slips
in mortar course of
plain clay tile

Spanish tiles

nail hole

250
mm

nail hole

110
mm

80
mm

200
mm

400 mm

150
mm

400 mm

channel tile (under)

cover tile (over)

Italian tiles

ridge tiles bedded in
mortar on roof tiles

channel tiles
nailed to boards

ridge board

plain tiles in
mortar

end lap 75 mm

75 × 25 mm
battens at
325 mm
centres

roofing
felt

roof boarding

rafter

soffit

fascia
board

one course of
plain tiles at eaves

end of
cover tiles
filled with
tile slips
in mortar

Figure 6.32   Single lap tiles.

pantile   single roman tile   double roman tile
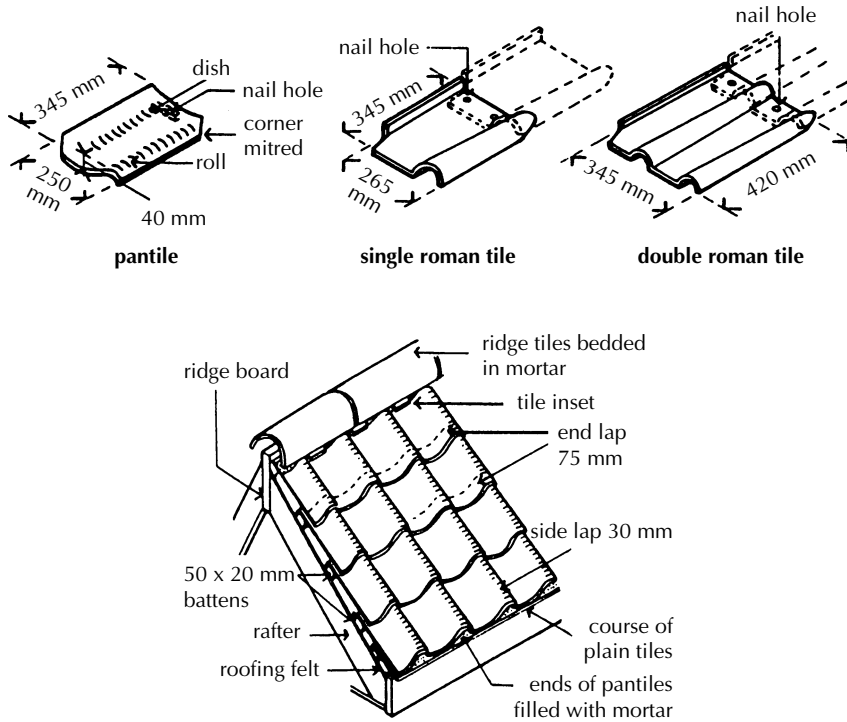
Figure 6.33   Pantiles.

Interlocking single lap tiles

By careful selection of clay or sand and cement and machine pressing, different types of clay and concrete interlocking tiles are produced. Grooves in the vertical long edges of tiles are designed to interlock under and over the edges of adjacent tiles to exclude wind and rain. A range of profiles is made from the interlocking double pantile to the flat pantile illustrated in Figure 6.34. There is a wider range of concrete than clay pantiles because of the difficulty of controlling shrinkage of clay during firing to produce a satisfactory interlock at edges.

There is no accepted standard size of interlocking tile although they are of similar size of about 420 mm long by 330 mm wide for concrete and about 320 mm long by 210 mm wide for clay. These comparatively thick tiles are made with nibs and hung on 38 by 25 mm sawn softwood battens on a roofing felt underlay on rafters at a pitch of from $15°$ to $22\frac{1}{2}°$. A single end lap of 75 mm is usual with the side butt lap dictated by the system of interlock, as illustrated in Figure 6.35.

These tiles are not usually made with nail holes, instead a system of aluminium clips is used. The aluminium clips hook over an upstand side edge at

interlocking tile
min pitch 15°

interlocking - double
pantile min pitch $22^1/_2$°

interlocking tile
min pitch $22^1/_2$°

flat interlocking tile
min pitch $17^1/_2$°
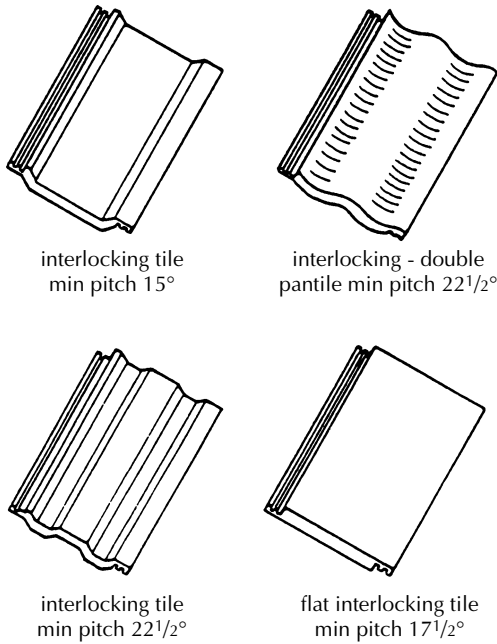
Figure 6.34   Interlocking tiles.

tile slips

half round ridge tile bedded in
mortar on tiles

interlocking
concrete roof tiles
end lap min
75 mm hung on
battens

trussed rafter

detail at ridge

roofing felt

38×25 mm
tiling
battens

aluminium clips hooked to side lock
and nailed to back of batten

at verge tiles are bedded in mortar on
tile slips on fibre cement sheet to
overhang gable wall 50 mm

aluminium
verge clips

gable end
cavity wall

detail at
eaves

fascia
board

half round gutter

fascia board

Figure 6.35   Interlocking tiles.

A   **Truss rafters ready to receive sarkin felt and roof battens.**

B   **Ventilator installed over rafters at eaves.**

C   **Interlocking single tiles fixed to battens.**

D   **Cavity tray protruding from wall. Lead flashing will be inserted under the trays and lapped over the tiles.**

Photograph 6.3   Roof construction with single lap tiles.

the head of a tile, under the end lap, and are nailed or screwed to the back edge of battens. Clips are used in every course in severe exposure or every other course or more for less exposed conditions. At the ridge (Figure 6.36) a half round ridge tile is bedded in mortar with end joints pointed. At the eaves a course of plain tiles provides a bed for mortar filling to the open ends of profiled tiles. Alternatively a number of proprietary 'dry' systems are available that allow the eaves and sometimes the ridge to be constructed without the use of cement mortar.

Ridge tile with ventilator
bedded mortar (5 mm gap)

Single lap interlocking
tiles

75 mm (min) lap

Timber tile battens

Plastic cross flow ventilator
ensures 25 mm (min)
air gap to roof space

Sarking (or breathable
roofing membrane) turned
into gutter

Fascia board

Soffit with disc or slot type
ventilator allowing
equivalent continuous
ventilation

Cavity fully sealed with calcium
board or full insulation (min)

Figure 6.36   Typical ridge detail – interlocking tiles.

At hips and valleys profiled tiles have to be cut to fit either under hip tiles or to a lead lined gutter to valleys. Because of the thickness of the tiles they have to be cut mechanically to provide a neat edge.

Slates

Thin slabs of natural stone have for many centuries been a traditional roof covering material in areas where natural stone can be split and shaped as a slate. These have traditionally come from Wales and Cumbria (Westmorland), although more recently it has become common to import slates from overseas where production costs are cheaper. The thickness, size and durability of slate depends on the nature of the stone and its ease of splitting into a useable size. Owing to the nature of the stone, the slates have irregular thickness, which can range from 4 to 10 mm for thin dense slates and 30 to 40 mm for thick stone tiles ('stonewolds'). Slate sizes are 600 × 300, 500 × 250, 450 × 225 and 400 × 200 mm.
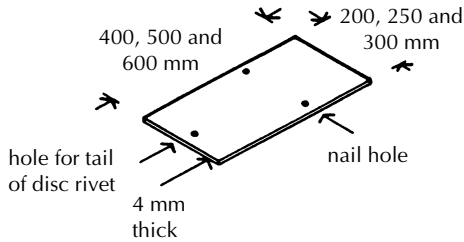
Figure 6.37 Fibre cement slate.

Reclaimed slates

Because of the considerable cost of new slates it has been practice for some years to use reclaimed slates recovered from demolition work. The disadvantage of these reclaimed slates is that they may vary in quality, be damaged by being stripped from old roofs and there is little likelihood of recovering the slate and a half width slates necessary to complete the bond at verges and abutments.

Slate substitutes

From the middle of the twentieth century, slates made from asbestos fibres, cement and water were used as cheap substitutes for natural slates. They are now made with natural and synthetic fibres, often incorporating slate dust for an authentic and more durable finish. These slates are made from pigmented cement and water, reinforced with natural and synthetic fibres. The wet mix is compressed to slates, which are cured to control the set and hardening of the material. The standard slate is 4 mm thick, with a matt coating of acrylic finish and a protective seal on the underside against efflorescence and algal growth. The standard slate is rectangular and holed for nail and rivet fixing. Standard fibre cement slates are made in sizes of 600×300, 500×250 and 400×200 mm, as illustrated in Figure 6.37, with a comprehensive range of fittings for ridge, eaves, verges and valleys. The standard fibre cement slate is uniform in shape, colour and texture. Fibre cement slates have a life of about 30 years in normal circumstances.

Fixing natural slates

Slates are nailed to 50×25 mm sawn softwood battens with copper composition or aluminium nails driven through holes, which are punched in the head of each slate. Galvanised steel nails should not be used as they will in time rust and allow the slates to slip out of position. Two holes are punched in each slate some 25 mm from the head of the slate and about 40 mm in from the side of the slate, as illustrated in Figure 6.38.

The battens are nailed across the roof rafters over roofing felt and the slates nailed to them so that at every point on the roof there are at least two thicknesses of slate, and so that the tail of each slate laps 75 mm over the head of the slate
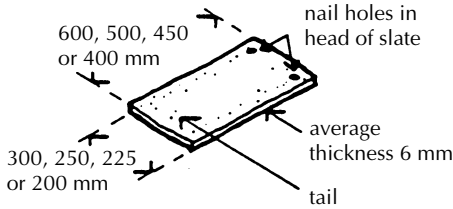
Figure 6.38   Natural slate.

two courses below. This is similar to the arrangement of plain tiles and is done for the same reason. Because the length of slates varies and the end lap is usually constant it is necessary to calculate the spacing or gauge of the battens. The formula for this calculation is:

$$Gauge = \frac{Length\ of\ slate - (\text{lap} + 25)}{2}\ \text{mm}$$

For example, the gauge of the spacing of the battens for 500 mm long slates is:

$$Gauge = \frac{500 - (75 + 25)}{2} = 200\ \text{mm}$$

The 25 that is added to the lap represents the 25 mm that the nail holes are punched below the head of the slate so that the 75 mm end lap is measured from the nail hole.

Figure 6.39 is an illustration of natural slates head nailed to preservative treated softwood battens with an end lap of 75 mm and the side butt joints
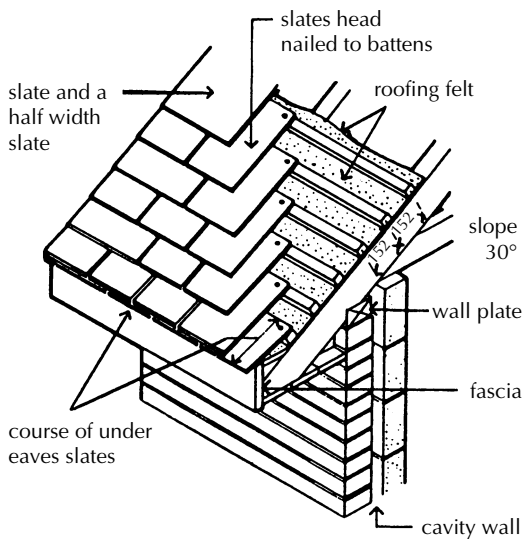
Figure 6.39   Head nailed slates.
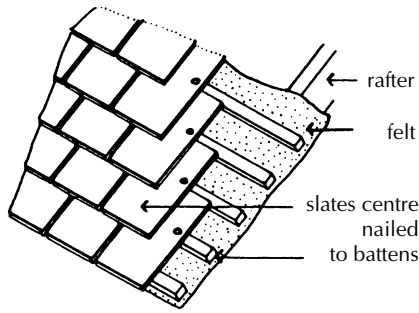
Figure 6.40   Centre nailed slates.

between slates breaking joint up the slope of the roof. The roof is pitched at 25°
to the horizontal, which is the least slope generally recommended for slates. At
verges a slate, which is one and a half times greater than the standard width of
slates, is used in every other course (Figure 6.39). Oversized slates avoid using
half width slate to complete the bond.

So that there shall be two thicknesses of slates at the eaves, a course of
undereaves slate is used. These slates are cut to a length equal to the gauge +
lap + 25 of the slating, as illustrated in Figure 6.39.

Slates are usually fixed by means of nails driven through holes in the head
of slates. This is the best method of fixing slates as the nail holes are covered
with two thicknesses of slate so that, even if one slate cracks, water will not get
in. But if long slates such as 600 mm are head nailed on a shallow slope of, say,
30° or less it is possible that in a high wind the slates may be lifted so much
that they snap off at the nail holes.

Centre nailed slates

In exposed positions on low pitch roofs it is common to fix the slates by centre
nailing them to battens. The nails are not driven through holes exactly in the
centre of the length of the slate, but at a distance equal to the gauge down from
the head of the slate, so that the slate can double lap at tails as illustrated in
Figure 6.40. With this method of fixing there is only one thickness of slate over
each nail hole so that if that slate cracks water may get into the roof.

Ridge

Common practice is to cover the ridge at the intersection of two slated slopes
with clay ridge tiles bedded in cement mortar. So that there is a double thickness
of slate a top course of slates is used at ridges. These shorter slates are usually
the gauge plus lap plus 50 or 75 mm long and head nailed to a double thickness
batten. Their ends are solidly filled with and joints pointed in cement mortar,
as illustrated in Figure 6.41.
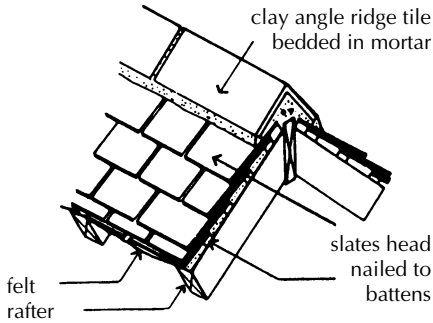
Figure 6.41   Tile ridge.

A somewhat more expensive, and durable, finish is to use a sheet lead ridge capping, as illustrated in Figure 6.42. A wood roll, cut from a 50 mm square softwood section, is nailed to the ridge board, which is deeper than usual. The lead (about 450 mm wide) is dressed around the wood roll and down the slates both sides. At joints between sheets of lead capping, there is a 150 mm overlap. To prevent the wings of the sheet lead being blown up in high wind, a system of 50 mm wide strips of sheet lead is nailed to the roll under the lead at 450 mm centres. These lead tacks are turned up and around the edges of the wings of the lead capping to keep them in place.

Hips
At hipped ends of a roof, slates and one and a half width slates in every other course are cut to the splay angle up to the hip. The hip is then weathered with clay ridge tiles bedded in cement mortar or with a sheet lead capping similar to the ridge capping.
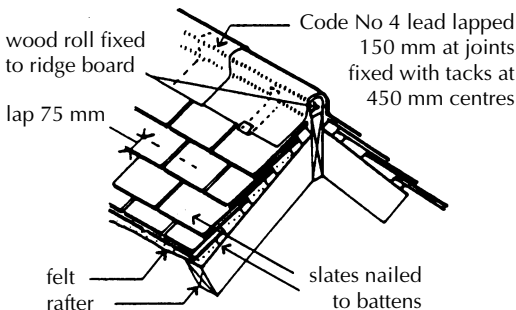
Figure 6.42   Lead ridge.
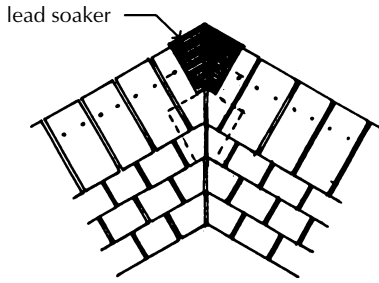
lead soaker

Figure 6.43   Slate valley.

Valleys

At the internal angle intersection of slated roof slopes the full and one and a half width slates are splay cut up to the valley. A system of shaped lead soakers is used to weather the mitred valley. A shaped lead soaker cut from Code No. 4 sheet lead is hung over the head of each course of slates. A similar soaker is hung over the head of slate courses above to overlap the soaker below, as illustrated in Figure 6.43. Careful cutting of slates and the careful arrangement of bonding of slates will create a neat, mitred, watertight valley.

Fixing fibre cement slates

Fibre cement slates are fixed double lap up the slope of roofs pitched at a minimum slope of $20°$ with a usual slope of $25°$ to the horizontal. The slates are fixed with the double end lap used with natural slates. The end lap may be the usual 75 mm, which is usually increased to 100 mm to provide cover for the centre nail fixing and the rivet hole. These comparatively thin, brittle slates are centre nailed to avoid cracking the slate. Each slate is nailed with copper composition or aluminium nails to 38×25 mm or 50×25 mm, impregnated, sawn softwood battens nailed over roofing felt to rafters, as illustrated in Figure 6.44. The gauge, spacing, of battens is calculated by the same formula used for natural slates.

   To secure these lightweight slates against wind, uplift copper disc rivets are used. The disc of these rivets fits between slates in the under course and the tail of the rivet fits through a hole in the tail of the slate above. The tail of the rivet is bent up to hold the slate in position, as illustrated in Figure 6.44. At verges and square abutments, one and a half width slate are used in every other course to complete the bond of slates up roof slopes. At eaves, two under eaves courses of slate are used. These cut or specially made short lengths of slate are head nailed to battens, as illustrated in Figure 6.44. At the ridge, special flanged end, fibre cement angle ridges are used. These 900 mm long ridge fittings are weathered by the overlap of the flanged ends, as illustrated in Figure 6.45, and secured as illustrated with screws and plastic washers. The wings of the ridge

disc rivets fit between slates
tail of rivet bent up to hold
tail of slate above

slate and a
half width
slate at
verge

fibre cement slates,
centre nailed to battens

copper disc rivets
to hold down tail
of slates

insulation

insulation

cavity wall

under eaves
courses of slate
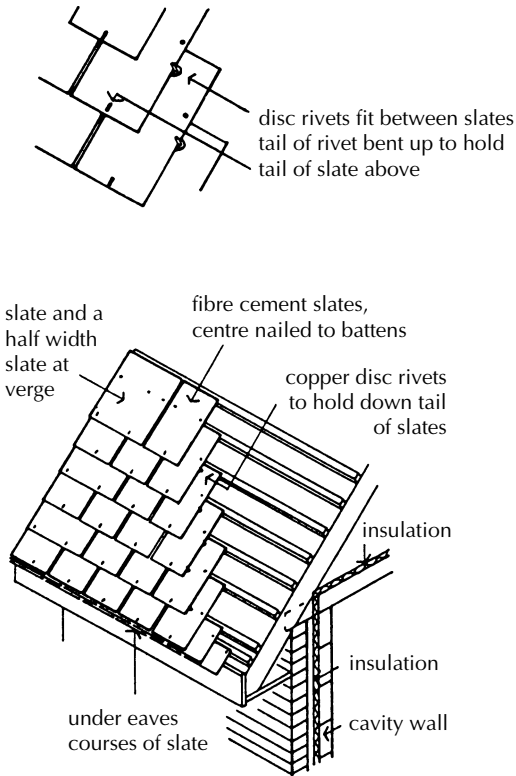
Figure 6.44   Fibre cement slating.

flanged end
of ridge

900 mm long fibre cement
ridge fixed to top batten with
screws and plastic washers

two top
courses
of slates
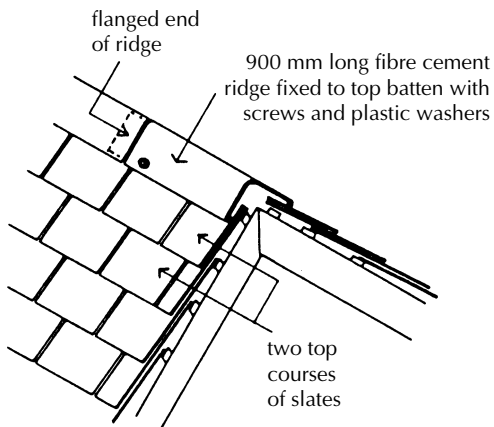
Figure 6.45   Fibre cement slate ridge.

fittings bear on the back of an under ridge course of slates without the need for cement and sand pointing. At hips and valleys the slates are mitre cut to fit up to the hip or valley and the mitre cut slates weathered with lead soakers hung over the head of slates.

6.4 Sheet metal covering to low pitch roofs

A low-pitched roof has slopes of from 10° to 30° to the horizontal and may serve as a good compromise between flat and more steeply pitched roofs. The principal coverings for low pitched roofs are copper and aluminium strips 450 or 600 mm wide, both of which are comparatively light in weight and therefore do not require heavy timbers to support them. Complicated and labour intensive joints (such as drips or double lock cross welts or other horizontal joints) are avoided by using strips with lengths up to 8.0 m. Because of the great length of each strip the fixing cleats used to hold the metal strips in position have to be designed to allow the metal to contract and expand freely.

Standing seams
Both copper and aluminium sheet are sufficiently malleable (workable) to be bent and folded without damage to the material. The strips of metal are jointed by means of a standing seam joint, which is a form of double welt and is left standing up from the roof as shown in Figure 6.46. The completed standing
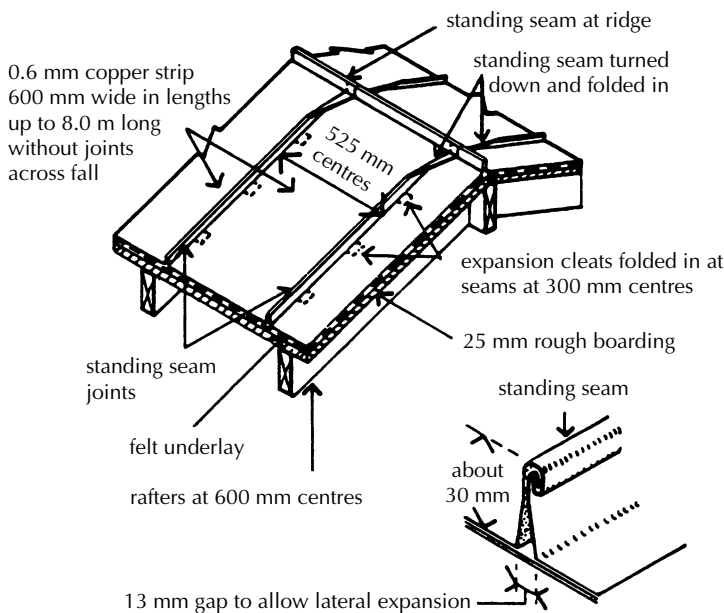
Figure 6.46   Copper standing seam roofing.
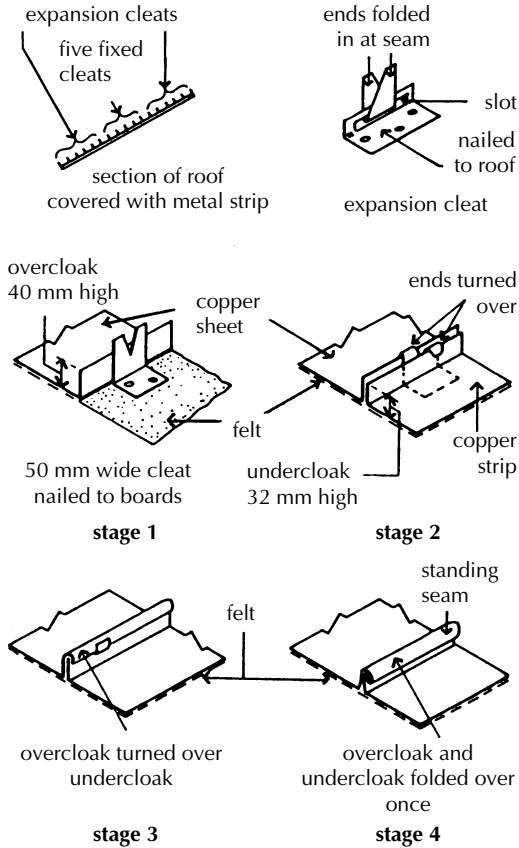
Figure 6.47   Holding down cleats.

seam is constructed so that there is a gap of some 13 mm at its base, which allows the metal to expand without restraint, as illustrated in Figure 6.46. The lightweight metal strips have to be secured to the roof surface at intervals of 300 mm along the length of the standing seams. This close spacing of the fixing cleats is necessary to prevent the metal drumming due to uplift in windy weather.

Two types of cleats are used: fixed cleats and expansion cleats. Five fixed cleats are fixed in the centre of the length of each strip and the rest of the cleats are expansion cleats. Figure 6.47 illustrates the arrangement of these cleats. The fixed cleats are nailed to the roof boarding through the felt underlay and Figure 6.47 illustrates the formation of a standing seam and shows how the fixed cleat is folded in. The expansion cleats are made of two pieces of copper strip folded together so that one part can be nailed to the roof and the second piece, which is folded in at the standing seam, can move inside the fixed piece.
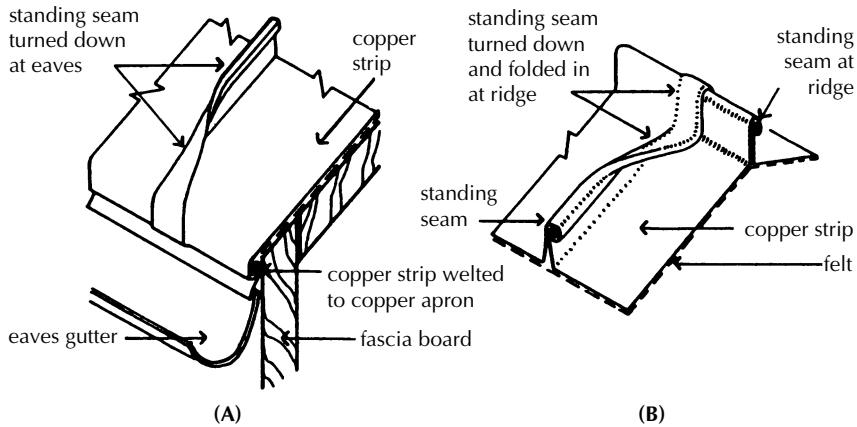
Figure 6.48   (A) Eaves. (B) Ridge.

The ridge is usually finished with a standing seam joint, as illustrated in Figure 6.48A, but as an alternative a batten roll or conical roll may be used. Whichever joint is used at the ridge, the standing seams on the slopes of the roof have to be turned down so that they can be folded in at the ridge. This is illustrated in Figure 6.48B. Because copper and aluminium are generally considered to be attractive coverings to roofs, the roof is not hidden behind a parapet wall, and the roof slopes discharge to an eaves gutter, as illustrated in Figure 6.48A.

Where the slope of the roof finishes at the parapet or wall, the strips of metal are turned up as an upstand and finished with an apron flashing. This is illustrated in Figure 6.49, which also illustrates the cutting and turning down of the standing seam. The verge of low-pitched roofs can be finished with batten roll or conical roll, as illustrated for flat roof coverings.
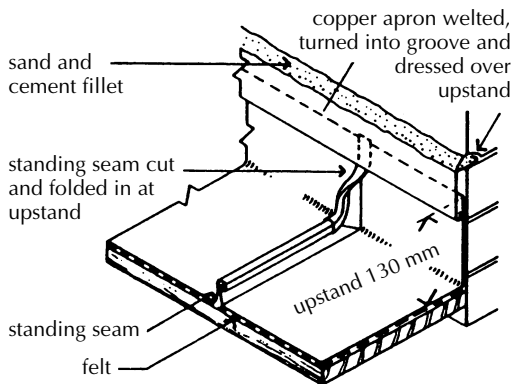
Figure 6.49   Upstand.

Felt underlay

Strip metal coverings must be laid on an underlay (bitumen felt or similar) laid across the roof boards and nailed to the boards with butt side joints. The felt allows the metal strips to expand and contract freely as they respond to changes in temperature.

6.5 Thermal insulation to pitched roofs

In the latest requirements in Approved Document L to the Building Regulations, when considering the roof as a single element there should be a maximum U value of:

❑ 0.2 W/m^2 K for roofs without a loft
❑ 0.16 W/m^2 K for roofs with a loft space
❑ 0.25 W/m^2 K for flat roofs with integral insulation (see flat roofs)

Two approaches

There are two approaches to insulating pitched roofs: constructing either a 'cold roof' or a 'warm roof', as noted earlier.

Cold roof

The most convenient, economical and usual place for insulation in a pitched roof is either across the top of, or between, the ceiling joists. With insulation at ceiling joist level the roof is described as a cold roof.

The materials most used for cold roof insulation are mineral wool mats or rolls of fibreglass or rockwool spread across or between the joists or loose fill spread between the joists on top of the ceiling finish. The most straightforward way of providing a layer of insulation is to spread rolls of mineral fibre across the top of ceiling joists right across ceilings in both directions and extended up to and overlapping insulation in walls, as illustrated in Figure 6.50. So that the layer of insulation is continuous over the whole of the ceiling area it is recommended that loft hatches (illustrated in Figure 6.51), giving access to roof spaces, be insulated and draught sealed, and that where service pipes penetrate ceiling finishes some effective form of draught seal be formed. All water carrying service pipes, water storage cisterns or tanks inside cold roof spaces must be effectively protected with insulating material (lagging) against the possibility of damage from the water freezing.

With mats or rolls of mineral fibre spread across ceiling joists there is a possibility of the loose material being compressed and losing efficiency as an insulator, especially under walkways in roof spaces. Boarded access inside roofs should, therefore, be raised on battens above the level of the insulation. The disadvantage of spreading or laying mineral fibre insulation or insulation

Ventilation at ridge

The area above the insulation will be cold

A layer of insulation is continuous up the cavity over the eaves and on top of the ceiling.

Care should be taken to ensure that there is ventilation at the eaves and ridge

Breathable sarking will help to avoid condensation forming within the roof space

Ventilation at the eaves

Cavity fully sealed with continuous sock filled with insulation (mineral wool)
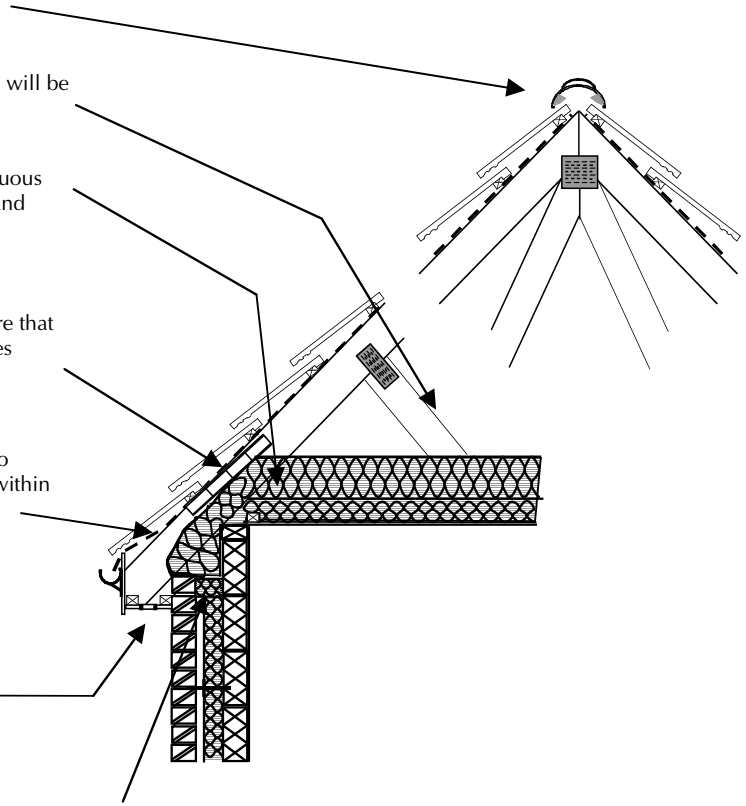
Figure 6.50   Cold roof: continuous insulation across ceiling.

mineral wool insulation laid between rafters

rafters trimmed around opening

rigid insulation fixed to top of blockwork hatch

hatch bolted or latched to compress draught seal

plaster board
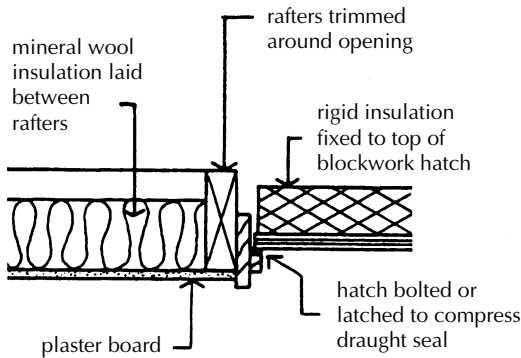
Figure 6.51   Insulation to loft hatch.

boards between ceiling joists is that there will be a deal of wasteful cutting in fitting the material closely between joists. Where insulation is fixed between joists an allowance for the different thermal conductivity of wood should be made.

Warm roof

A more expensive place to fix insulation is above, between or below the rafters of a pitched roof (Figure 6.52). Because the area of a pitched roof surface is greater than that of a horizontal ceiling there is a greater area to cover with insulation. The advantage of this arrangement is that the roof space will be warmed by heat rising from the heated building below and will, in consequence, be comparatively warm and dry for use as a storage place. With the insulation at roof level the roof is described as a warm roof.

The most practical and economic place to fix insulation for a warm roof is on top of rafters where there will be the least wasteful cutting of the thin, expensive, insulation boards. However, the latest robust details show insulation on top of, and between, roof rafters (similar to that shown in Figure 6.52), which improves thermal resistance. The insulation on top of the rafters should cover the whole area of the roof preventing any cold bridges. The rigid insulation
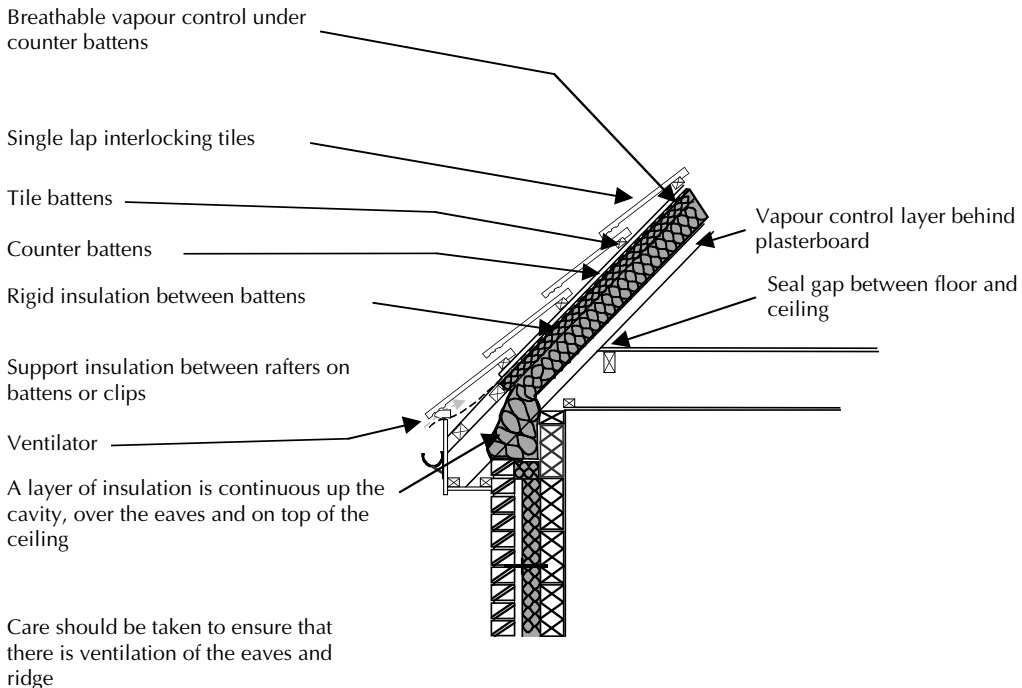
Figure 6.52   Warm pitched roof – detail of insulation.

boards, which are placed on top of the rafters, also act as a form of sarking excluding the wind that would otherwise blow through tiled and slated roofs. To limit thickness, a material with a high thermal resistance, such as XPS, PIR or PUR, is used. These insulation boards are nailed directly to the roof rafters with their edges close butted or with tongued and grooved edges for a tight fit. Roofing felt is spread over the insulation boards and sawn softwood counter battens are nailed through the insulation boards to rafters to provide a fixing for tiling or slating battens.

Vapour check

To control the movement of warm moist air from inside a building to the cold side of insulation, it is practice to fix a layer of some impermeable material, such as polythene sheeting, to the underside of insulation. Water vapour on the warm side of insulation is normally not a problem as there are no cold surfaces for the condensation to form on. However if water vapour is allowed to penetrate to cold areas of the building or structure the air will not be able to hold the moisture and condensation will form on the cold surfaces. By definition a vapour check is any material that is sufficiently impermeable to prevent the movement of moisture vapour without being an impenetrable barrier (may allow the passage of air, but not moisture laden air). The usual form of vapour check is sheets of 250 gauge polythene sheet with the edges overlapped and spread under insulation over ceiling joists with edges taped around pipes and cables that penetrate ceiling finishes.

Some insulating materials, such as the organic, closed cell boards, e.g. extruded polystyrene, are substantially impermeable to moisture vapour. When these boards can be close butted together or provided with rebated or tongued and grooved edges and cut and close fitted to junctions with walls and seals around pipes, they will serve as a vapour check. However, site practice is rarely so precise and it is advisable to have a vapour check on the warm side of insulation. Breathable sarking that lets water vapour from inside the roof escape, but which prevents water and wind penetrating from outside the dwelling can also be used.

Ventilation

A requirement from Part F to the Building Regulations is that adequate provision be made to prevent excessive condensation in a roof (there is no definition of what constitutes 'excessive'). Cold roof spaces should be adequately ventilated to outside air to reduce the possibility of condensation. A more rational approach to reducing the possibility of warm, moist air penetrating a cold roof space is the recommendation for provision of both background and mechanical extract ventilation to kitchens and bathrooms as recommended in Approved Document F.
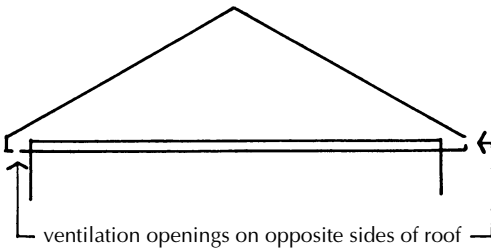
Figure 6.53   Roof ventilation.

Cold roof spaces should have ventilation openings to promote cross ventilation, as illustrated in Figures 6.53 to 6.55. The suppliers of tiles and slates offer a range of special fittings to provide roof ventilation through eaves, ridge and in roof slopes. A typical under eaves ventilator for slate is illustrated in Figure 6.54. The plastic ventilator is fixed between roof rafters before the roofing felt is laid. It is fitted with insect screens over openings that provide ventilation to roofs. The roofing felt and slate are laid over the ventilators. A sufficient number of ventilators are used to provide the requisite ventilation area to comply with the regulations.
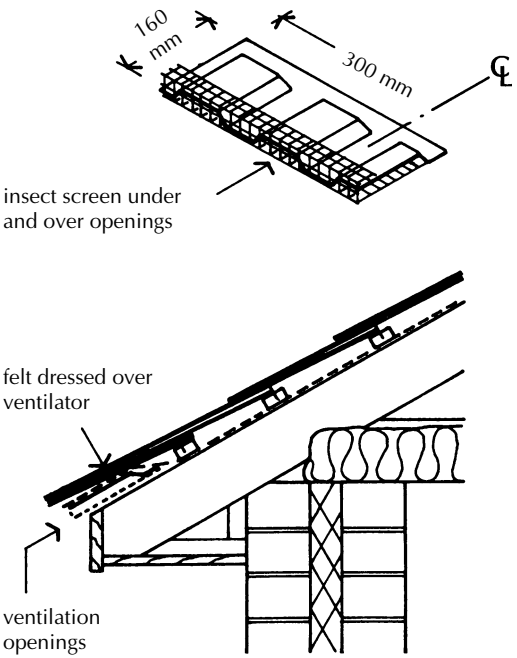
Figure 6.54   Under eaves ventilator.

**A Roof pitch exceeds 35°
or span exceeds 10 m**

B Room in roof space

C Roof pitch less than 15°

D Roof pitch greater than 15°
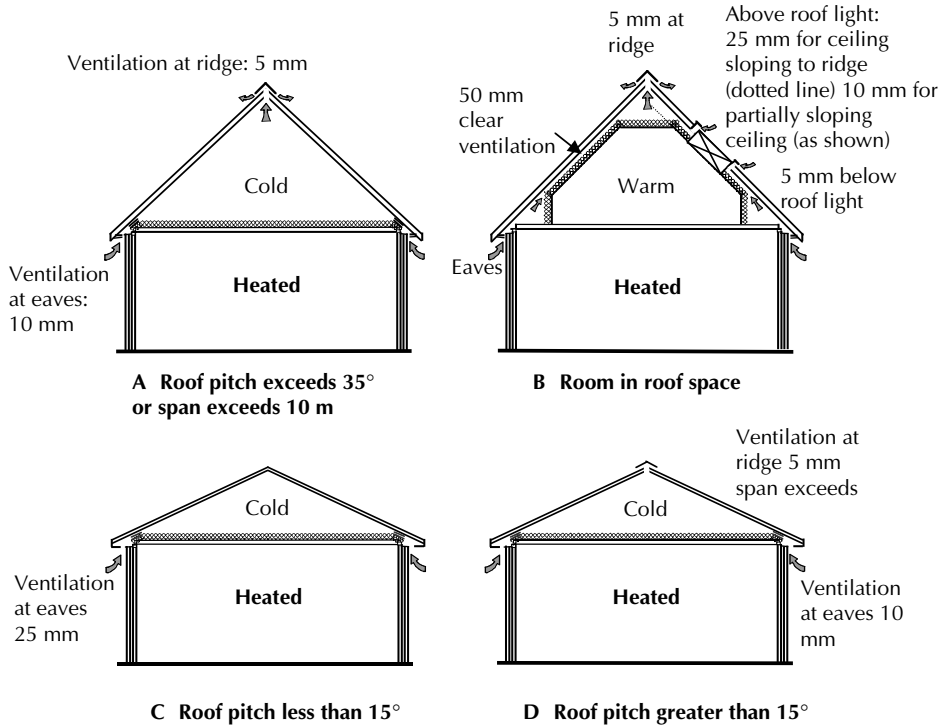
Figure 6.55   Pitched roof ventilation.

The NHBC (2003) Standards state that all roof voids should be ventilated to prevent condensation. Figure 6.55 shows illustrations of the guidance provided in the NHBC Standards.

Uncontrolled ventilation
Care should be taken not to over ventilate a property. There is no guidance on the maximum level of ventilation; however, it would be wrong to over ventilate a building when attempts are being made to seal all other parts of the building structure. The increased emphasis on airtight buildings is to seal the building and only allow air to escape into and out of the building by prescribed ventilation duct. This approach provides controlled ventilation, ventilation controlled by design and not defects that allow air to leak between the structure.

6.6 Flat roofs

A roof is defined as flat when its weather plane is finished at a slope of 1° to 5° to the horizontal. The shallow slope to flat roofs is necessary to encourage rainwater to flow towards rainwater gutters or outlets and to avoid the effect

known as ponding. Where there is no slope or fall or a very shallow slope it is possible that rainwater may not run off the roof. The increase in load generated by rain pooling may cause the roof to deflect leaving the rainwater lying in a shallow pond. This water pressure may in time cause deterioration of the roof membrane.

The minimum falls (slope) for flat roof coverings are 1:60 for copper, aluminium and zinc sheet, and 1:80 for sheet lead and for mastic asphalt and built-up bitumen felt membranes. To allow for deflection under load and for inaccuracies in construction it is recommended that the actual fall or slope should be twice the minimum and allowance be made where slopes intersect so that the fall at the mitre of intersection is maintained.

Lead, copper and zinc sheet are laid as comparatively small sheets dressed over rolls at junctions of sheet (down the slope of the roof) and with small steps (drips) at junctions of sheet across the slope. The size of the sheet is limited to prevent excessive expansion and contraction that might otherwise cause the sheet to tear. The upstand rolls down the slope and the steps or drips across the slope provide a means of securing the sheets against wind uplift and as a weathering to shed water away from the laps between sheets. More recently aluminium sheet has also been used.

Because of the cost of the material, and the very considerable labour costs involved in covering a roof with these metals, the continuous membrane materials, asphalt and bitumen felt, came into use early this century. Asphalt is a dense material that is spread while hot over the surface of a roof to form a continuous membrane, which is impermeable to water. It is generally preferred as a roof covering to concrete flat roofs. Bitumen impregnated felt is laid in layers bonded in hot bitumen to form a continuous membrane that is impermeable to water. Bitumen felt is comparatively lightweight and commonly preferred for timber flat roofs for that reason. Both asphalt and bitumen felt will oxidise and gradually become brittle and have a useful life of at most 20 years. Bitumen felt becomes brittle in time and may tear due to expansion and contraction caused by temperature fluctuations. Of recent years, fibre-based bitumen felts have lost favour due to premature failures and polyester-based felts are now more used for their greater durability.

6.7 Timber flat roof construction

The construction of a timber flat roof is similar to the construction of a timber upper floor. Sawn softwood timber joists 38 to 75 mm thick and from 97 to 220 mm deep are placed on edge, spaced at 400 to 600 mm centres, with the ends of the joists built into or on to or against brick walls and partitions. Tables in Approved Document A give sizes of joists for flat roofs related to span and loads for roofs with access only for maintenance and repair and also for roofs not limited to access for repair and maintenance. Strutting should be

fixed between the roof joists to provide lateral restraint as described for upper timber floors.

Flat roof construction

Roof deck

Boards that are left rough surfaced from the saw are the traditional material used to board timber flat roofs. This is called rough boarding and is usually 19 mm thick and cut with square, that is plain, edges. Plain edged rough boarding was the cheapest obtainable and used for that reason. Because square edged boards often shrink and twist out of level as they dry, chipboard or plywood is mostly used today to provide a level roof deck. For best quality work, tongued and grooved boards were often used.

End support of joists

If there is a parapet wall around the roof, the ends of the roof joists may be built into the inner skin of cavity walls or supported in metal hangers. The joists can bear on a timber or metal wall plate or be packed up on slate or tile slips as described for upper floors. The ends of the roof joists are sometimes carried on brick corbel courses, timber plate and corbel brackets or on hangers in precisely the same way that upper floor joists are supported. The end of roof joists built into solid brick walls should be given some protection from dampness by treating them with a preservative.

Timber firring

Flat roofs should be constructed so that the surface has a slight slope or fall towards rainwater outlets. The sloping surface is created with the use of firring pieces. These consist of either tapered lengths of fir (softwood) nailed to the top of each joist or varying depth lengths of softwood nailed across the joists, as shown in Figure 6.56.

tapered firring pieces nailed to top of joists

varying height firring pieces nailed across joists
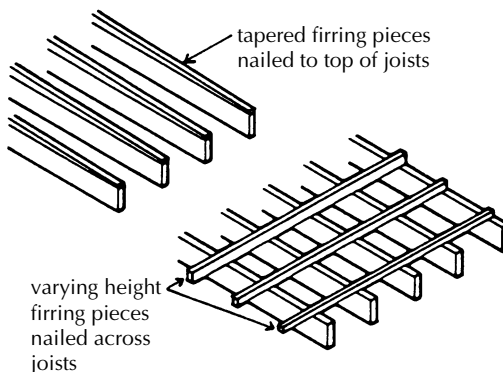
Figure 6.56   Firring to timber flat roof.

Varying depth firring is used where rough boarding is fixed as the deck for flat roof sheet metal coverings. By this arrangement the boards are fixed down the slope so that any variation in the surface of the boards, due to shrinkage or twisting, does not impede the flow of rainwater down the shallow slope. Tapered firring is used where the roof deck is formed by chipboard or plywood sheets nailed to firring with close butted edges to form a level surface. As an alternative to timber firring, insulation boards that are made or cut to a shallow wedge section can be used to provide the necessary shallow fall.

Sheet metal covering to timber flat roofs

Sheet metal is used as a covering because it gives excellent protection against wind and rain; it is durable and lighter in weight than asphalt, tiles or slates. Four metals in sheet form are used: lead, copper, zinc and aluminium.

Sheet lead

Lead is a heavy metal that is comparatively soft, has poor resistance to tearing and crushing and has to be used in comparatively thick sheets as a roof covering. It is malleable and can easily be bent and beaten into quite complicated shapes without damage to the sheets. Lead is resistant to all weathering agents including mild acids in rainwater in industrially polluted atmospheres. On exposure to the atmosphere, a film of basic carbonate of lead oxide forms on the surface of the sheets. These films adhere strongly to the lead and, as they are non-absorbent, they prevent further corrosion of the lead below them. The useful life of sheet lead as a roof covering is upwards of a hundred years.

Rolled sheet lead for roof work is used in thicknesses of 1.8, 2.24 and 2.5 mm. These thicknesses are described as Code Numbers 4, 5 and 6 respectively, the Code corresponding to the Imperial weight of a given area of sheet. No sheet of lead should be larger than 1.6 m² so that the joints between the sheets are sufficiently closely spaced to allow the metal to contract without tearing away from its fixing. Another reason for limiting the size of sheet, which is peculiar to lead, is to prevent the sheet from creeping down the roof under gravity.

The joints across the fall of the roof are made in the form of a 50 mm drip or step down to encourage flow of water. To reduce excessive increases in the thickness of the roof due to these drips, they are spaced up to 2.3 m apart and the rolls (joint longitudinal to fall) 600 to 800 mm apart. Figure 6.57 illustrates part of a lead covered flat roof showing the general layout of the sheets and a parapet wall around two sides of the roof.

Wood rolls

The edges of sheets longitudinal to the fall are lapped over a timber, which is cut from lengths of timber 50 mm square to form a wood roll. Two edges of the batten are rounded so that the soft metal can be dressed over it without
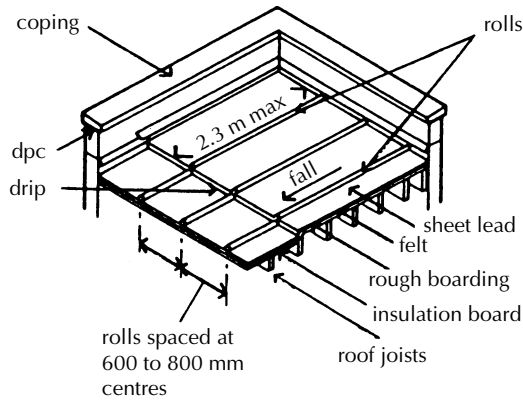
Figure 6.57   Lead flat roof.

damage from sharp edges. Two sides of the batten are slightly splayed and the waist so formed allows the sheet to be clenched over the roll. Figure 6.58 is an illustration of a wood roll. An underlay of bitumen impregnated felt or stout waterproof building paper is first laid across the whole of the roof boarding and the wood rolls are then nailed to the roof at from 600 to 800 mm centres. The purpose of the underlay of felt or building paper is to provide a smooth surface on which the sheet lead can contract and expand freely.

The edges of adjacent sheets are dressed over the wood roll in turn. In sheet metalwork the word dressed is used to describe the shaping of the sheet. The edge of the sheet is first dressed over as underlap or undercloak and is nailed with copper nails to the side of the roll. The edge of the next sheet is then dressed
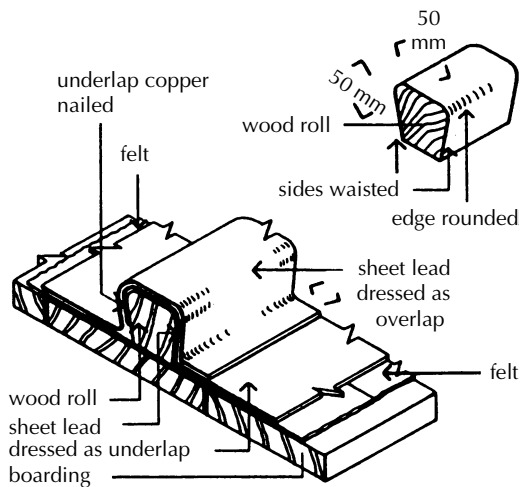
Figure 6.58   Wood rolls.

as overlap or overcloak. A section through one roll is shown in Figure 6.58. In this way no sheet is secured with nails on both sides, so that if it contracts it does not tear away from the nails.

Drips

Drips 50 mm deep are formed in the boarded roof by nailing a 50 × 25 mm fir batten between the roof boards of the higher and lower bays. The drips are spaced at not more than 2.3 m apart down the fall of the roof. The edges of adjacent sheets are overlapped at the drip (forming the underlap and overlap). The underlap edge is copper nailed to the boarding in a cross-grained rebate, as shown in Figure 6.59. An anti-capillary groove formed in the 50 × 25 mm batten is shown into which the underlap is dressed. This groove is formed to ensure that no water rises between the sheets by capillary action.

Figure 6.59 also shows the junction of wood rolls with a drip and illustrates the way in which the edges of the four sheets overlap. This arrangement is peculiar to sheet lead covering, which is a soft, very ductile material that can be dressed as shown without damage. The end of the wood roll on the higher level is cut back on the splay (called a bossed end) to facilitate dressing the lead over it without damage. This seemingly complicated junction of four sheets of lead, which provides a watertight overlap and makes allowance for thermal movement of lead, can be quickly made by a skilled plumber.

Where there is a parapet wall around the roof or where the roof is built up against a wall the sheets of lead are turned up against the wall about 150 mm as an upstand (no fixing is needed); 170 mm strips of sheet lead are then placed
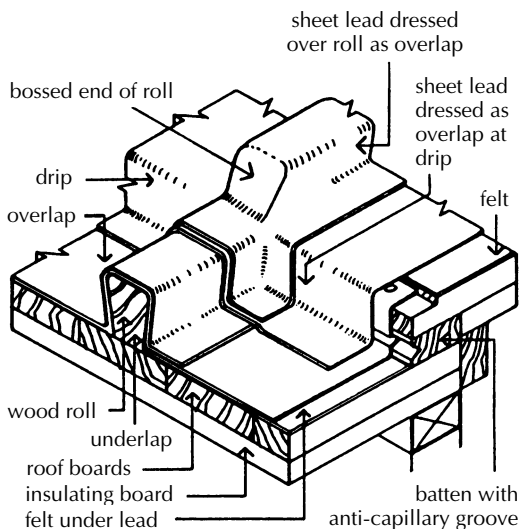
Figure 6.59   Drip.
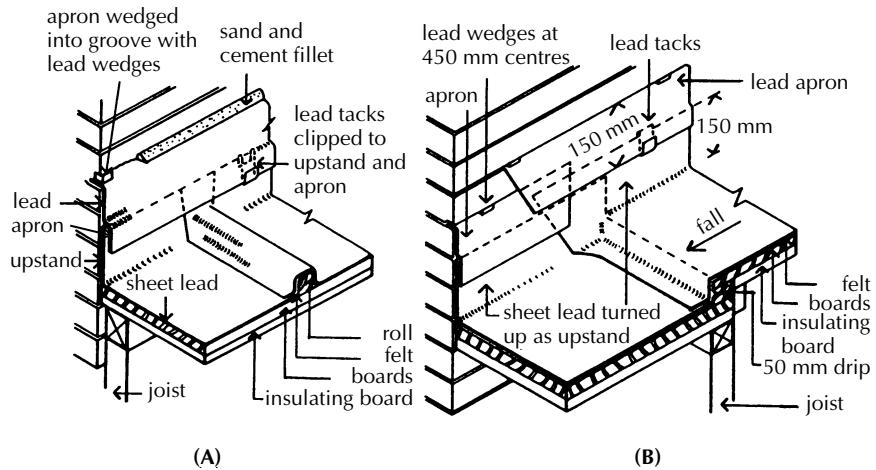
Figure 6.60   (A) Junction of roll and upstand. (B) Junction of drip and upstand.

into the rebated (raked) brickwork. The horizontal joint of the brickwork is cut or raked out (25 mm) deep enabling the lead to be tucked into the brickwork (water which runs down the face of the brickwork will not get behind or under the leadwork). To hold the strips in place wedges made of lead are used and the lead strip is folded down (dressed down) over the lower leadwork (upturned apron flashing). To prevent the apron from being blown up by the wind, lead clips are fixed as shown in Figures 6.60A and B.

Lead gutter

Where the lead flat roof is surrounded on all sides by parapet walls it is necessary to collect the rainwater falling off at the lowest point of the roof. A shallow timber framed gutter is constructed and this gutter is lined with sheets of lead jointed at drips and with upstand and flashings similar to those on the roof itself. The gutter is constructed to slope or fall towards one or more rainwater outlets. The gutter is usually made 300 mm wide and is formed between one roof joist, spaced 300 mm from a wall, and the wall itself (Figure 6.61).

The gutter bed is supported by 50 × 50 mm gutter bearers fixed at 450 mm centres supported by 50 × 25 mm battens which are nailed to the wall and the joist to provide the necessary fall in the gutter. Gutter boards, 19 mm thick, are fixed along the length of the gutter as a gutter bed.

Where the roof is surrounded by a parapet wall and a rainwater pipe can be fixed to the outside of the wall, an opening is formed in the wall as an outlet usually 225 × 225 mm square. A rainwater head is fixed to the wall below the outlet. The sheet lead gutter lining is continued through the outlet and dressed to discharge into the rainwater head. Both upstands to the gutter lining are dressed into the sides of the rainwater outlet in the parapet wall and dressed
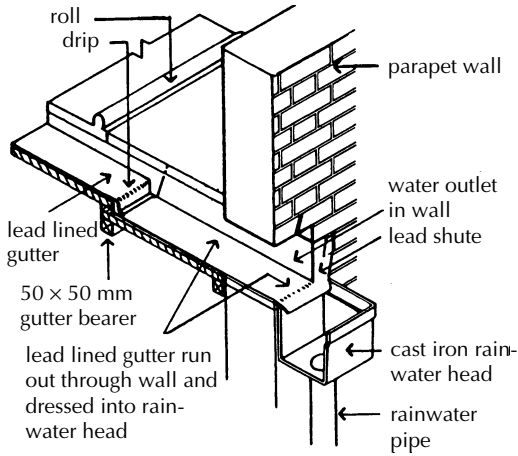
Figure 6.61   Rainwater outlet.

against the wall face to form a shute to direct water into the rainwater head, as illustrated in Figure 6.61.

Where it is not possible or desirable to fix a rainwater pipe and head externally the gutter has to be formed to discharge to a cesspool (Figure 6.62). The purpose of this lead lined box, cesspool or catchpit is as a reservoir so that, during a heavy storm, when the rainwater pipe may not be able to carry the water away quickly enough, the cesspool prevents flooding of the roof. A lead down pipe is connected to the cesspool and run down as a down pipe or
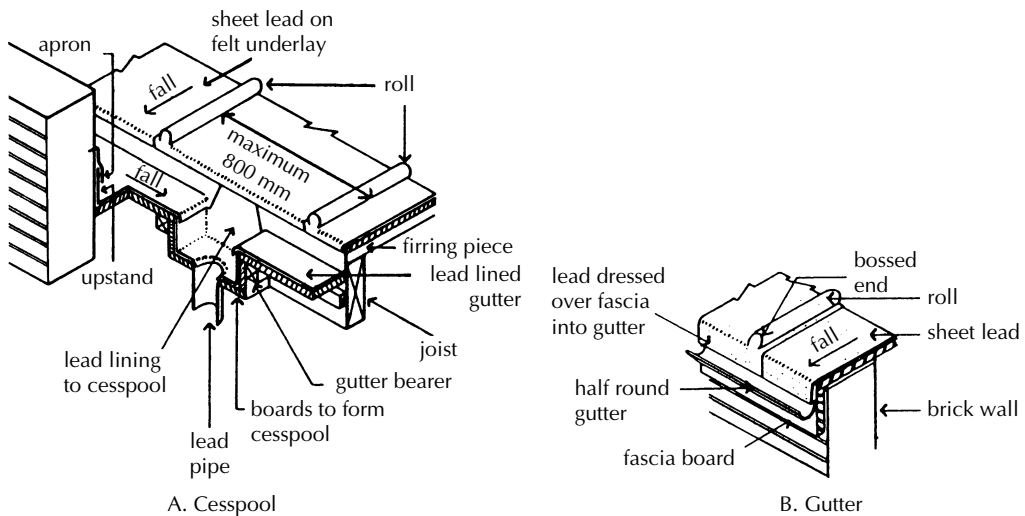
Figure 6.62   (A) Cesspool. (B) Gutter.

connected to a down pipe. Where there is no parapet wall on one side of the roof it can discharge rainwater directly to a gutter fixed to a fascia board on the external face of the wall. The lead flat roof covering is dressed to discharge into the gutter, as illustrated in Figure 6.62.

Copper sheet

Copper is a metal with good mechanical strength and is sufficiently malleable in sheet form that it can be bent and folded without damage. Copper is resistant to all normal weathering agents and its useful life as a roof covering is as long as that of lead.

The usual thickness of copper sheet for roofing is 0.6 mm. An oxide of copper forms on the surface of copper sheet and, in the course of some few years, the sheets become entirely covered with a light green compound of copper. This light green 'patina' is impervious to all normal weathering agents and protects the copper below it. The standard sizes of sheet supplied for roofing are 1.2 m and 1.8 m × 900 mm. The minimum fall for a copper covered roof is 1 in 60 and the fall is provided by means of firring pieces just as it is for lead covered roofs.

The traditional method of fixing copper sheet to a flat roof has been by the use of wood rolls down the shallow slope, over which adjacent sheets are shaped with welted joints and drips across the slope. Copper sheets for roofing, which cannot be shaped over rolls and drips as easily as can lead, are joined by the use of double lock welts, which are a double fold at the edges of adjacent sheets. These double lock welts are used for joints of sheet over the wood rolls and at joints across the fall, as illustrated in Figure 6.63. Because of the difficulty of forming a double lock welt it is necessary to stagger these joints to avoid the difficulty of forming this joint at the junction of four sheets of copper.

Figure 6.64 is an illustration of a copper sheet covered flat roof. The wood rolls along the fall of the roof are fixed at centres to suit the standard width of sheet, for example 750 mm. At drips the rolls are staggered to avoid welts at the junction of four sheets. Drips are formed across the slope at from about
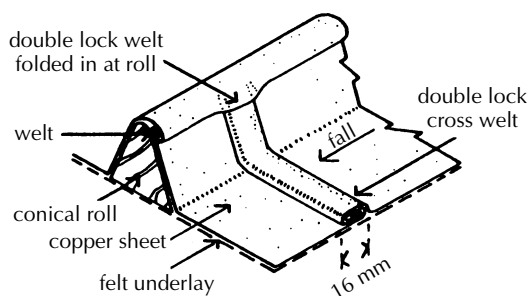
Figure 6.63   Double lock welt.
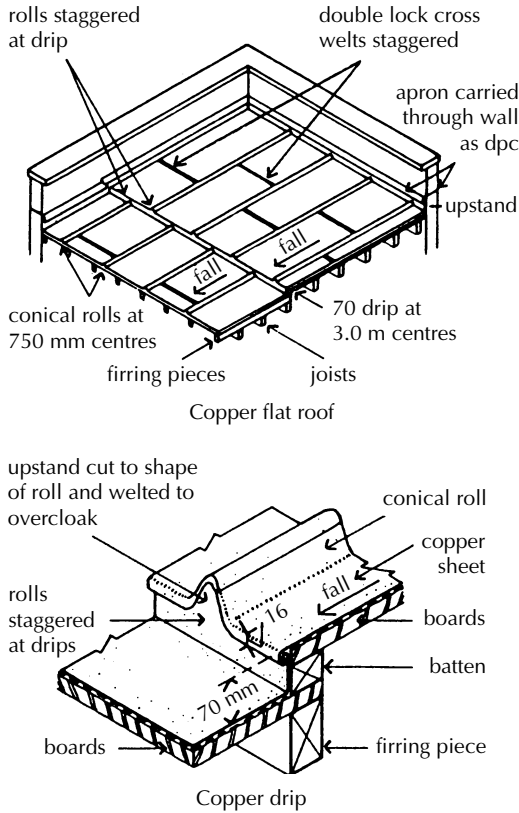
Figure 6.64   **Copper sheet roof.**

2 to 3 m to suit the size of standard sheet with staggered double lock cross welts between drips and drip and parapet wall. Drips are formed with a 40 × 50 mm batten, which is nailed between the upper and lower roof boarding on the firring pieces on joists, as illustrated in Figure 6.64.

At the drip, the sheets of copper are welted with the upstand of the lower sheet shaped to the end of the roll and welted to the overcloak as illustrated in Figure 6.64. The conical rolls formed down the fall of the roof are formed around 63 × 50 mm sections of softwood, which are shaped in the section of a cone with a round top. The shape is selected to facilitate shaping the metal. The wood rolls are nailed through a felt underlay to the roof boarding and also 50 mm wide strips of copper sheet at 450 mm centres as cleats. The felt underlay serves to allow the sheets to expand and contract without restraint.

The copper strips are used to restrain the sheets against wind uplift by being folded into the welted joint formed over the roll, as illustrated in Figure 6.65. At upstands to parapet walls the sheets are turned up at the upstand and covered with an apron flashing which is wedged into a brick joint. At the junction of
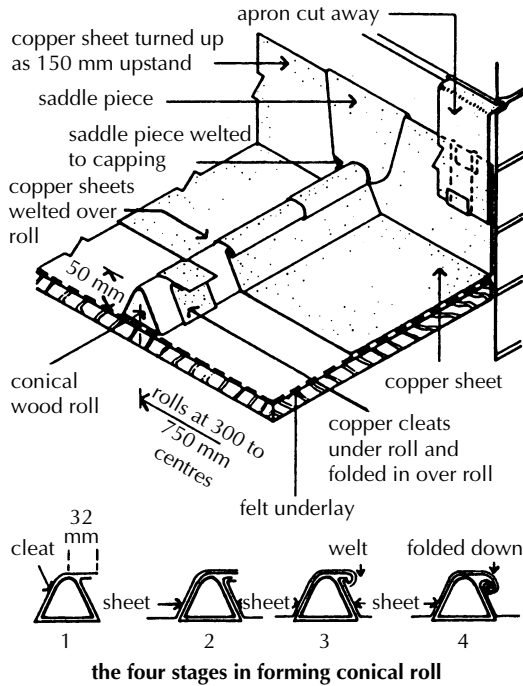
Figure 6.65   Conical roll.

the conical roll and the upstand it is necessary to use a separate saddle piece of copper sheet that is welded to the capping and dressed up to cover the joint between adjacent upstands, as illustrated in Figure 6.65.

The copper covered roof may discharge to a verge gutter or to a parapet wall gutter formed in the roof and lined with copper. As an alternative to the use of a conical roll down the slope or fall of copper roofs a batten roll may be used with drips and double lock cross welts across the fall or slope of the roof. A wood roll with slightly shaped sides is nailed through a felt underlay and also 50 mm wide strips of copper at 450 mm centres as cleats. The sides of adjacent sheets of copper are shaped as upstand sides to the roll and the roll is covered with a separate strip of copper as a capping. The cleats are folded into the double lock welts formed between the upstand of sheets and the edges of the capping. This is the type of joint longitudinal to falls that is also used with zinc sheet roof covering.

Zinc sheet
Zinc, a dull, light grey metal, is used in sheet form as a covering for timber flat roofs. It is the cheapest of the metals used for roofs and has been extensively used in northern European countries, but less so in the UK. Zinc sheet
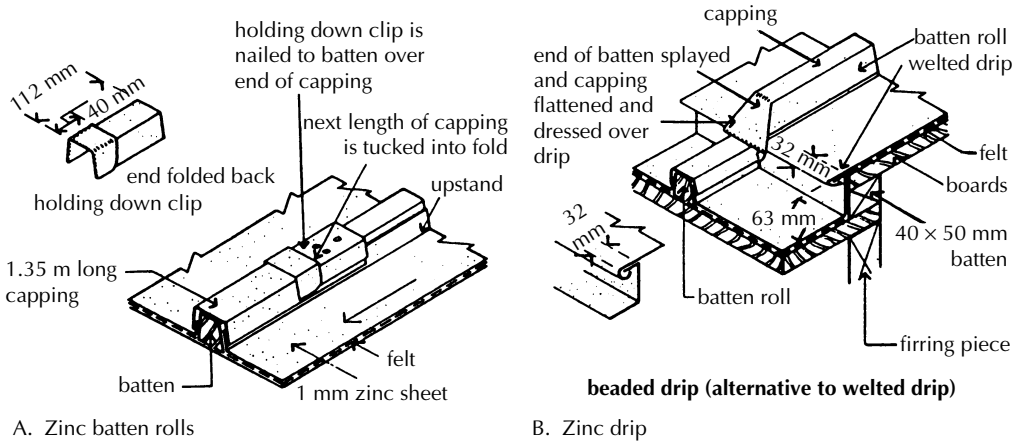
Figure 6.66   (A) Zinc batten rolls. (B) Zinc drip.

is appreciably more difficult to bend and fold than copper. Being a brittle material it is liable to crack if bent or folded too closely. Standard 2.4 m, 900 mm and 1 or 0.8 mm thick sheets are bent up to the sides of softwood batten rolls. The batten rolls are nailed at 850 mm centres through felt underlay and clips at 750 mm centres. The clips are welted over the upstand edges of the sheets.

Because of the difficulty of making a double lock welt of zinc sheet the capping is shaped to fit over the batten rolls. The lower edges of the capping are bent in, feinted, to grip the sheets. To secure the capping, zinc holding down clips are nailed to the batten over the end of a lower capping and the end of the upper capping tucked into the fold, as illustrated in Figure 6.66A. Drips are formed across the slope at 2.3 m intervals, with beaded drips and splayed cappings to roll ends, as illustrated in Figure 6.66B. At parapets the sheets are turned up as upstand and covered with a zinc apron that is wedged into a brick joint. The end of a batten capping is folded and flattened to cover the edges of adjacent sheets.

Waterproof membranes for timber flat roofs

The two materials that have been used as a waterproof membrane for timber framed roofs are asphalt as a continuous membrane and bitumen felt laid in layers to form a membrane or skin.

Mastic asphalt

Asphalt is described in the relevant British Standard as mastic asphalt. The material, which is soft and has a low softening (melting) point, is an effective barrier to the penetration of water. Asphalt is manufactured either by crushing

asphalt finished over lead strip nailed to roof

asphalt dressed over half-round wood roll

asphalt in two coats to a finished thickness of 20 mm

fascia

asphalt apron

soffit

cavity wall

rough boards

joist

insulation

firring piece

sheathing felt

Asphalt covered flat roof

asphalt

sheathing felt

boards

strip of lead sheet welted and nailed to boards

joist

half round gutter

fascia

Detail at eaves

Figure 6.67   Asphalt covered flat roof.

natural rock asphalt and mixing it with natural lake asphalt, or by crushing natural limestone and mixing it with bitumen whilst the two materials are sufficiently hot to run together. The heated asphalt mixture is run into moulds in which it solidifies as it cools. The solid blocks of asphalt are heated on the building site and the hot plastic material is spread over the surface of the roof in two layers breaking joint to a finished thickness of 20 mm. As it cools it hardens and forms a continuous, hard, waterproof surface.

If there is no parapet wall around the roof it is usually designed to overhang the external walls, to give them some protection, and the asphalt drains to a gutter over the strip of sheet lead, which is dressed down into a gutter, as illustrated in Figure 6.67.

If the roof has parapet walls around it, or adjoins the wall of a higher building, an asphalt skirting or upstand, 150 mm high, is formed and this skirting is turned into horizontal brick joints purposely cut about 25 mm deep to take the
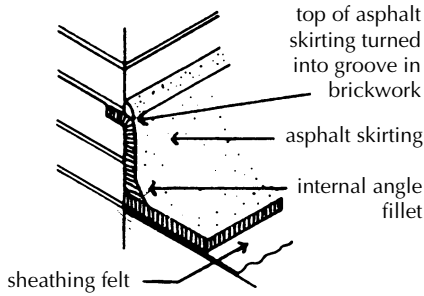
Figure 6.68   Asphalt skirting.

turn-in of the asphalt skirting, as illustrated in Figure 6.68. For strengthening, an internal angle fillet is run at the junction of the flat and the asphalt skirting. An alternative detail is to form the skirting as an upstand only, with the upstand weathered by a sheet lead apron that is wedged into a raked out brick joint and dressed down over the upstand. The advantage of this finish is that structural, thermal or moisture movements of the roof are less likely to cause cracking of the asphalt either at the internal angle fillet or at the turn in the wall.

It is essential that asphalt be laid on an isolating membrane underlay so that slight movements in the structure are not reflected in the asphalt membrane. A properly laid asphalt covering to a roof will not absorb water at all and any rainwater that does lie on it due to ponding will eventually evaporate. The asphalt is laid to a slight fall, of at least 1:80, so that the rainwater drains away to a rainwater outlet or gutter. Asphalt is a comparatively cheap roof covering and if the asphalt is of good quality and is properly laid it will have a useful life of some 20 years or more. The asphalt should be renewed about every 20 years if the roof is to remain watertight.

Built-up bitumen felt roofing
The word felt is used for fibres that are spread at random around a large, slowly rotating drum on which a mat of loosely entwined fibres is built up. The mat is cut, rolled off the drum and compressed to form a sheet of felted (matted) fibres. For use as a roof surface material the felt is impregnated or saturated with bitumen. A variety of felts is made from animal, vegetable, mineral or polyester fibre or filament for use as flat roof covering.

Sheathing and hair felts
These felts are made from long staple fibres, loosely felted and impregnated with bitumen (black felt) or brown wood tars or wood pitches (brown felt). They are used as underlays for mastic asphalt roofing and flooring to isolate the asphalt from the structure.

Fibre base bitumen felts

Fibre base bitumen felts are the original material used as covering for the pitched roofs of sheds and outhouses, in either one or two layers. These felts are made as a base of animal or vegetable fibres that are felted, lightly compressed and saturated with bitumen. Fine granule surfaced felts may be used as a lower layer in built-up roofing and as a top layer on flat roofs that are subsequently surfaced with bitumen and mineral aggregate finish as a comparatively cheap roof finish.

Mineral surfaced fibre base felt is finished on one side with mineral granules for appearance and protection for use as a top layer on sloping roofs. Fibre base bitumen felts have been used as a covering for small area pitched roofs. The material is either bonded to a boarded finish with bitumen in two layers, breaking joint or nailed and bonded at joints and edges for the first coat and bonded with bitumen as a top coat.

Glass fibre based bitumen felts

Glass fibre based felts have for many years largely replaced natural fibre based felts as the material used for built-up felt roofing for flat roofs. The material is made from felted glass fibres that are saturated and coated with bitumen.

The felted glass fibre base forms a tenacious mat that is largely unaffected by structural, thermal and moisture movement of the roof deck and does not deteriorate as a result of moisture penetration. The fine granule coated, glass fibre based felt is used as underlay and as a top layer on flat roofs that are subsequently surfaced with bitumen and mineral aggregate. Mineral surfaced glass fibre based felts may be used as a top layer on flat roofs as a low cost finish and on sloping roofs as a finish layer. A perforated, glass fibre based felt is produced for use as a venting first layer on roofs where partial bonding is used. The durability of glass fibre based felt depends principally on the bitumen with which it is saturated. In time the bitumen coating will oxidise on exposure to the radiant energy from the sun, harden, and ultimately crack and let in water. A layer of insulation under the felt will appreciably increase the rise in temperature and expansion of the surface and so accelerate the cracking of the hardened top surface. A layer of a light colour mineral aggregate dressed over the surface will provide some protection from the sun. The serviceable life of this weathering is of the order of 20 to 30 years.

Polyester base bitumen felts

A polyester base of staple fibre or filament, formed by needling or spin bonding, is impregnated with bitumen. The fibre or filament base of polyester has higher tensile strength than the true felt bases. Because of this greater strength this 'felt' is better able to withstand the strains due to structural, thermal and moisture movement without the rupture that a flat roof covering will suffer.

The fine granule surfaced felt is used as a base, intermediate or top layer of built-up roofing, which is to be subsequently covered with bitumen and

mineral aggregate finish. The mineral surface felt is for use as a top layer where there is no additional surface treatment. Polyester base felt, which is generally used for the three layers of built-up roofing, is sometimes used as a top coat to underlays of glass fibre based felt.

High performance roofing

High performance bitumen coated bases are made with a polyester fabric that is coated with polymer modified bitumen. The bitumen is modified with styrene butadiene styrene (SBS) or atactic polypropylene (APP) to provide improved low temperature flexibility, improved creep resistance at high temperatures and greatly improved fatigue endurance to the bitumen. These high performance bitumen bases, which are generally used in two layers, are more expensive than other built-up roofings and are used for their appreciably improved durability.

Mineral surface dressing

The finished top surface of built-up felt roof covering is often finished with a dressing of mineral aggregate spread over a bitumen coating. The purpose of this mineral dressing is to act as a reflective, protective layer of light coloured particles to reduce the oxidising and hardening effect of direct sunlight on the bitumen bonding compound and also to improve the appearance of the roof. Light coloured mineral aggregate, graded in size from 16 to 32 mm, is spread to a thickness of at least 12.5 mm on a layer of bitumen. This also provides the necessary cover to prevent the surface spread of fire.

Laying built-up bitumen felt roofing

Bitumen felt is applied to flat roofs in three layers: the first, intermediate and top layers. Practice is to bond the first layer of felt to the roof deck with bitumen spread over the whole surface of the roof, or more usually in a system of partial bonding with bitumen to allow some freedom of movement relative to the roof. The rolls of felt are spread across the roof with a side lap of 75 mm minimum between the long edges of the rolls and with a head, or end, lap of at least 75 mm for felts and 150 mm for polyester based felts. To avoid an excessive build up of thickness of felt at laps, the side lap of rolls of felt is staggered by one-third of the width of each roll between layers so that the side lap of each layer does not lie below or above that of other layers, as illustrated in Figure 6.69.

Full bond

The traditional method of fixing felt roofing is by fully bonding the felt to the roof deck and the layers of felt to one another by the 'pour and roll' technique, in which hot bitumen is poured on the roof deck and the rolls of felt are continuously rolled out as the bitumen is poured. The pour and roll method of bonding is used for all three layers in the full bonding method and for the two
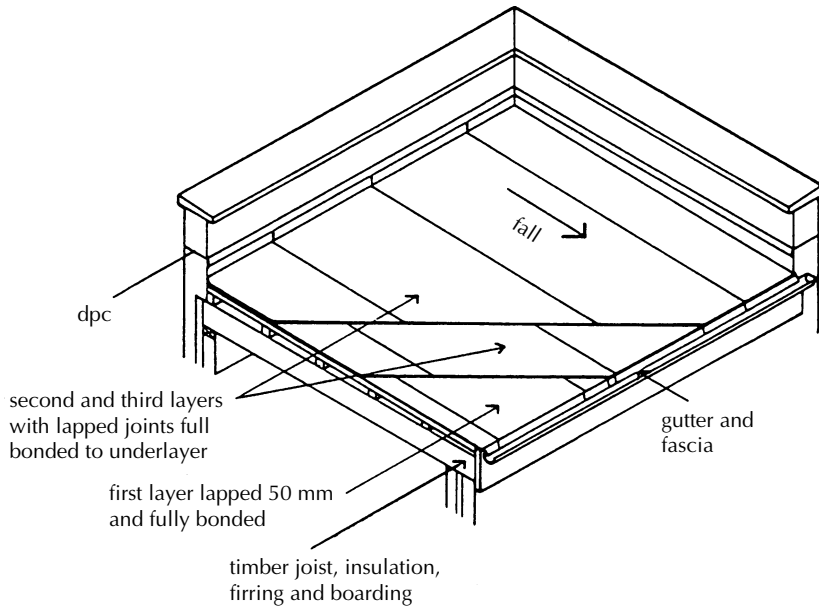
Figure 6.69   Built-up felt covering to timber flat roof.

top layers in the partial bond method. The purpose of the bitumen is initially to bond the first layer to the roof deck against wind uplift and then to bond the succeeding layers to each other and form a watertight seal at overlaps of rolls of felt. The full bond method is used where appreciable wind uplift is anticipated in exposed positions and the perforated bottom layer where wind uplift is low in sheltered positions that will also allow some freedom of movement of the felt relative to the roof.

Partial bond
Where it is anticipated that wind uplift will be moderate it is usual to use a perforated, glass fibre based felt as a first layer to allow some movement of the deck independent of the felt covering. The perforated first layer is laid loose over the deck and the intermediate layer is fully bonded to it. The hot bitumen bed will penetrate the perforated bottom layer to achieve a partial bond to the deck. The top layer is then fully bonded to the intermediate layer.

On a roof deck covered with insulation boards the method of bonding the first layer depends on the composition of the insulation. The majority of insulation boards either have a surface to which hot bitumen can be applied or are coated to assist the bond of bitumen. On polyurethane and polyisocyanurate boards, provision should be made for the escape of gases generated by the use of hot bitumen, by using a perforated venting first layer of felt that is laid loose over the boards.
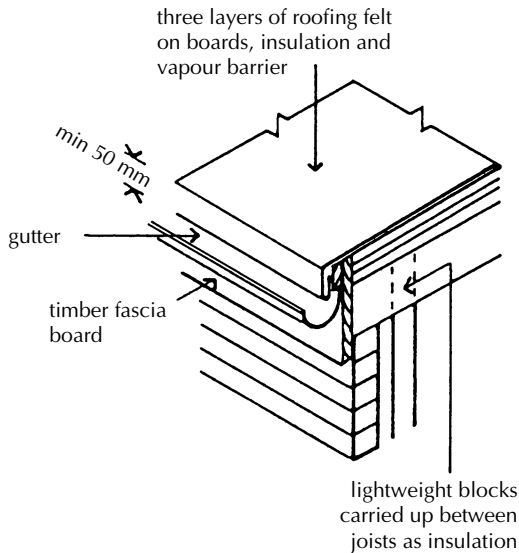
Figure 6.70 Eaves gutter.

Built-up bitumen felt roof coverings should be laid to a shallow fall so that rainwater will run off to a gutter. The most straightforward way of draining these flat roofs is by a single fall to one side to discharge directly to a gutter fixed right across one side of the roof, as illustrated in Figure 6.70. Here the roof is enclosed inside a parapet wall on three sides. The roof joist ends are carried over the wall to provide a fixing for a softwood timber fascia board, which supports a gutter (Figure 6.70). To direct the run-off of water into the gutter, a strip of felt is nailed to the fascia board, welted and then turned up on the roof and bonded between the first and intermediate layers of felt. Because felt is difficult to welt without damage, a strip of sheet lead may be used as an alternative to the felt strip. For continuity of insulation a lightweight insulation inner leaf of wall or cavity insulation is carried up to the level of the roof insulation.

At the junction of a felt covered flat roof and a parapet or a wall the top two layers of three-ply bitumen felt are dressed up the wall over an angle fillet as an upstand 150 mm high. The top of the felt upstand is covered with a lead flashing, which is tucked into a raked out brick joint and dressed over the upstand (Figure 6.71).

Single-ply roofing
For details of single-ply, polymeric roof membranes see *Barry's Advanced Construction of Buildings*.
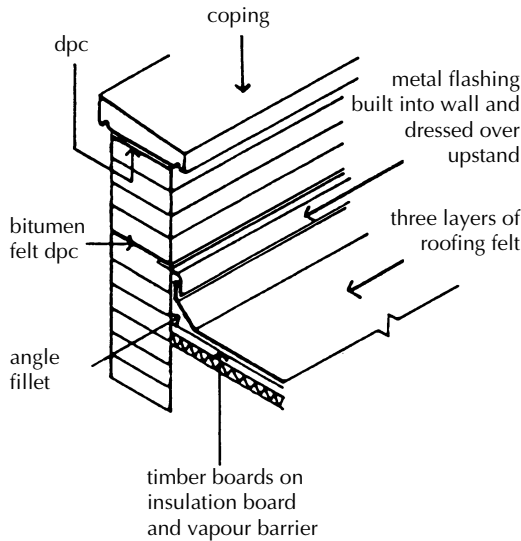
Figure 6.71   Upstand and flashing.

Inverted or upside down roof

An effective layer of insulation laid or fixed below flat roof coverings will appreciably increase the temperature fluctuations that a roof covering will suffer between hot days and cold nights. Bitumen felt coverings are particularly affected by direct sunlight, which causes oxidisation of the bitumen, which hardens and becomes brittle and liable to crack. The most rational place for the layer of insulation on a flat roof, particularly those covered with bitumen felt and, to a lesser extent, asphalt, is on top of the covering to reduce temperature fluctuations.

In this form of construction one of the organic closed cell insulation boards, which do not absorb water and are sufficiently dense to support the overlay of stones or paving slabs, are used. The roof covering may be laid to slight falls to rainwater outlets or laid flat to outlets. The insulation boards are laid on top of the roof covering. To protect the insulation against wind uplift the roof is covered with a layer of mineral aggregate, stones, of sufficient depth to hold the insulation in place. Where the flat roof serves as a terrace, paving stones are used as a loading coat (Figure 6.72). The paving stones are laid, open jointed, on a filter layer of dry sand or mineral fibre mat as a bed and filter for rainwater. To avoid heat flowing through the concrete roof structure and passing up the parapet wall (forming a thermal bridge) lightweight thermal concrete blocks should be used.

Rain falling on the roof will in part be retained by the stone or paving slab covering and the filter layer and will, in part, drain through the insulation

dpc – cavity tray

Aerated concrete block (aircrete), low density with good thermal resistance. Prevents cold bridge

Mineral aggregate

Filter layer

Paving slabs

Insulation

Bitumen felt

Cavity fill continues up the full height of the cavity
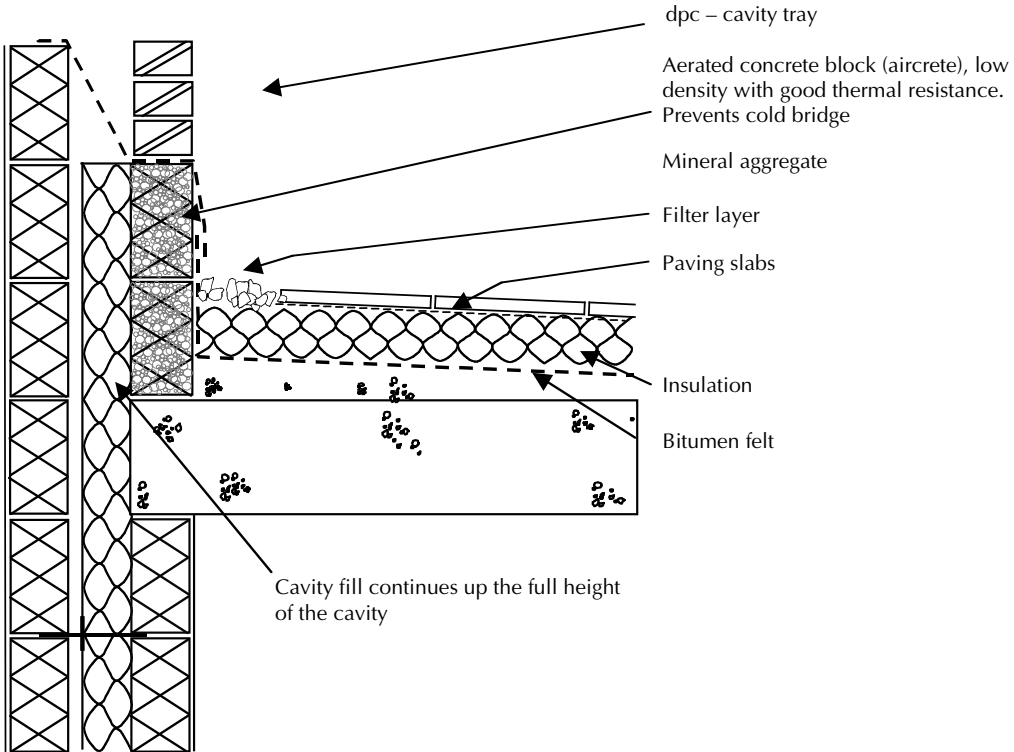
Figure 6.72   (A) Inverted roof abutting an internal wall.

to the covering. During dry periods much of the rain retained by the stones or paving slabs will evaporate. For access to clear any blockages that might occur in rainwater outlets it is wise to provide a margin, around the edge of the roof, of loose aggregate over a narrow strip of insulation that can be lifted to clear blockages. The disadvantage of the inverted roof is that where leaks occur in the covering the whole top layer may have to be removed. Because of the protection afforded by the two top layers, faults in the covering are less likely than with coverings laid on the insulation.

6.8 Concrete flat roofs

Reinforced concrete flat roofs for small buildings are constructed in the same way as reinforced concrete floors with hollow beam, beam and filler blocks or insitu cast concrete slab (see Chapter 4). Roofs are designed to support the self weight of the roof together with loading from rain and snow, resist

Aerated concrete block (aircrete), low density with
good thermal resistance. Prevents cold bridge.

dpc – cavity tray

Cavity fill continues up the full height of the
cavity
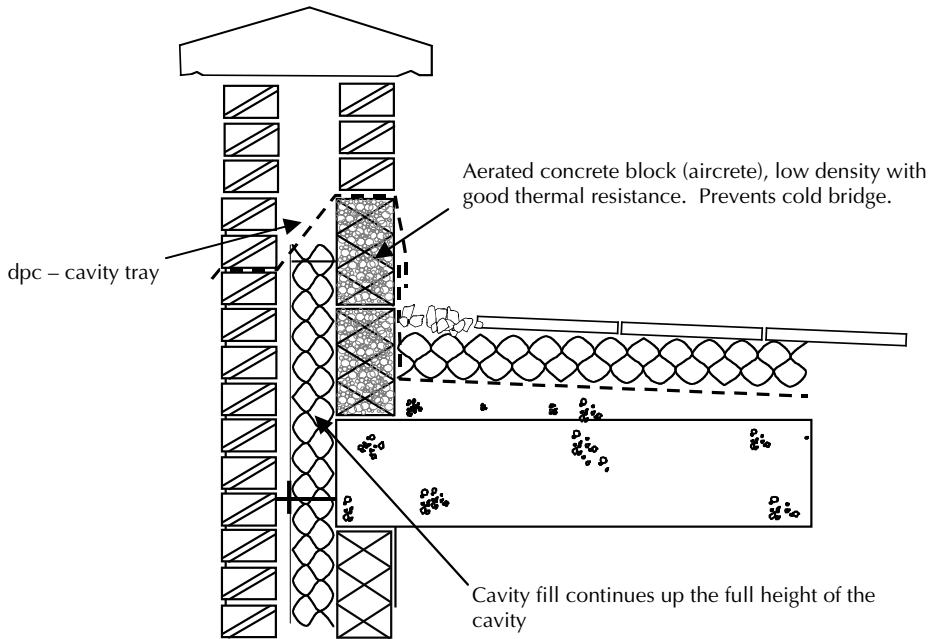
Figure 6.72   (B) Inverted roof abutting parapet wall.

wind pressure, and provide support for access for maintenance or for use as
a terrace. The concrete roof is supported on external walls with intermediate
support from internal loadbearing walls or beams as necessary.

Roof coverings

To provide a smooth level surface ready for the roof covering the concrete or
concrete topping may be power floated. More usually a cement and sand screed
is used, which can be spread and finished to the level or levels necessary to
provide a fall to drain rainwater from the roof. A screed can be finished to one
way, two way or four way falls to rainwater outlets with the necessary currents
at the intersections of falls.

Asphalt roof covering
The conventional wisdom is that asphalt is best suited as a covering to concrete
and felt to timber roofs. The sense is that the comparative stability and freedom
from shrinkage movement of concrete is best suited to the heavy, inflexible
nature of asphalt, whereas the lighter, more flexible nature of built-up bitumen
felt is better suited to a timber roof.

Hot asphalt is spread over a layer of loose laid sheathing felt on a dry screed
finish in two layers to a finished thickness of 20 mm. The asphalt is then covered
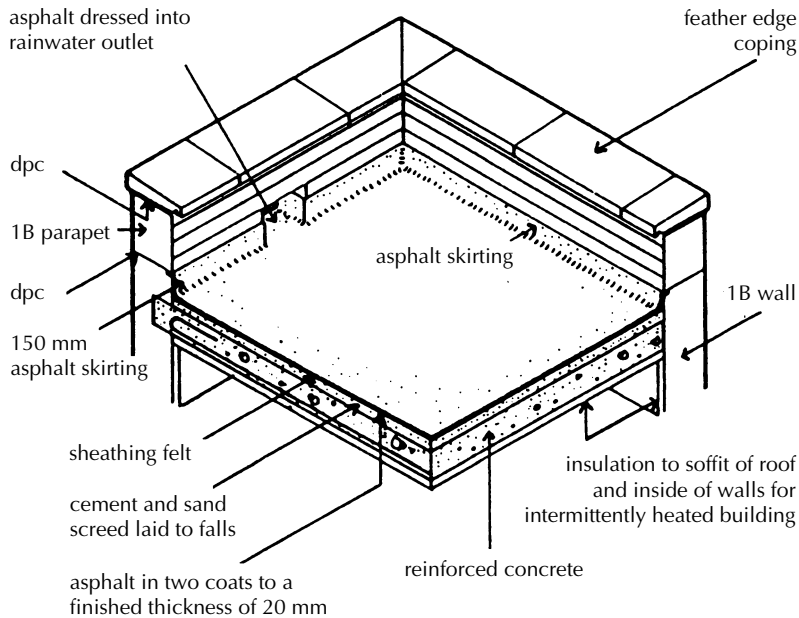
Figure 6.73   Asphalt covering to concrete flat roof.

with a dusting of dry, fine, sharp sand to absorb the 'fat' of the neat asphaltic bitumen that is worked to the surface by hand spreading. On a screed laid to falls the asphalt drains to outlets formed in parapet walls (Figure 6.73). The asphalt skirting is dressed into the outlet in the parapet over a lead chute dressed down over a rainwater head.

A reinforcing, internal angle, fillet of asphalt is formed at the junction of the flat roof and the parapet wall and the 150 mm high asphalt skirting. The top of the skirting may be turned into a groove cut in a horizontal brick joint (Figure 6.74). As an alternative the asphalt skirting may be run up the face of the wall by itself or over plastic vents placed at intervals to provide ventilation
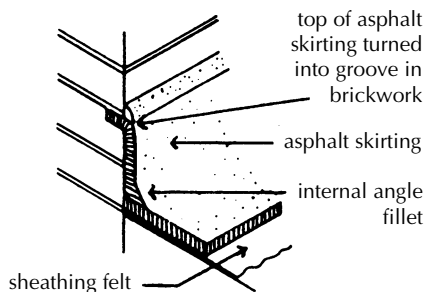
Figure 6.74   Asphalt skirting.

for moisture vapour. The top of the skirting is then covered with a sheet lead flashing, tucked into and wedged in a raked out brick joint and dressed down over the upstand asphalt skirting.

The spacing and size of skirting vents and the need and frequency of vents in the surface of the asphalt is indeterminate. First or second hand knowledge of past failures of asphalt by blisters may dictate the assumption of the need for vents rather than soundly based need.

Built-up bitumen felt covering

As a precaution against the possibility of water drying out from screeded concrete roofs and rising to the surface under bitumen felt coverings, expanding and causing blisters, it is usual to use the partial bonding method.

With the partial bonding method the first layer of felt is bonded to the surface of the screed with perimeter and intermediate strips of bitumen with 180 mm wide vents between the strips of bitumen to allow moisture vapour to vent to perimeter and central vents. The surface of the screed is first coated with a bitumen primer to improve the bond of bitumen to screed. Perimeter strips of bitumen 450 mm wide are spread around the roof with 150 mm wide vents at intervals for moisture vapour to vent to the perimeter. Strips of bitumen are spread over the body of the roof, as illustrated in Figure 6.75. The principal adhesion of the felt covering, against wind uplift, is effected by the perimeter bonding. The size and spacing of the strips of bitumen is chosen as a matter of judgement between the need for adhesion to keep the felt covering flat and the assumed need to provide ventilation paths for moisture vapour pressure.
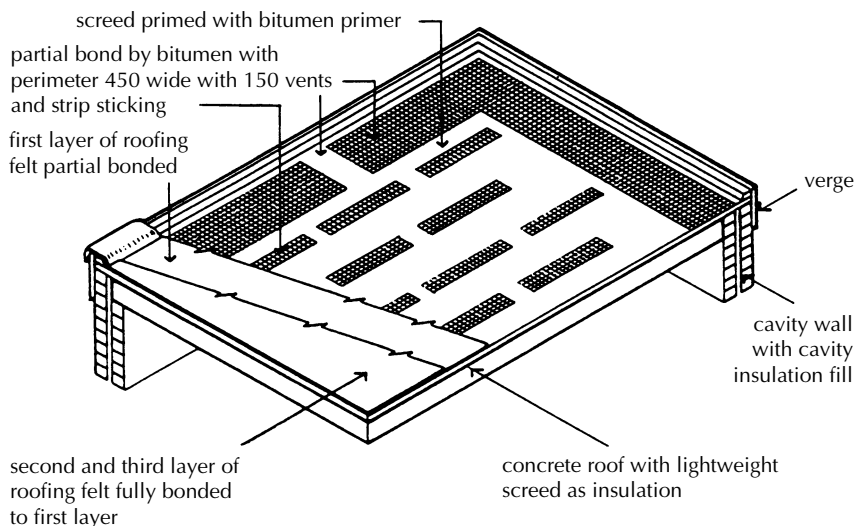
Figure 6.75   Partial bond of felt roofing to concrete.
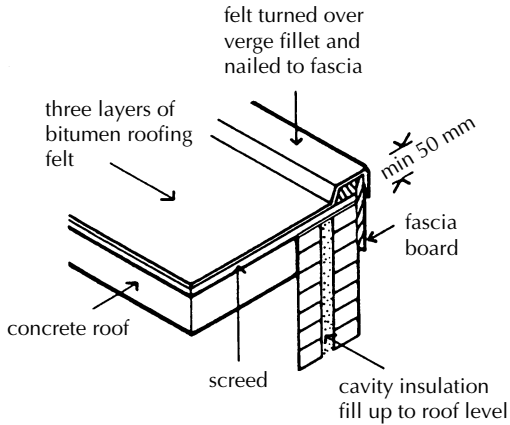
Figure 6.76   Verge.

At verges the intermediate and final layers of felt can be shaped over a splayed wood block and then covered with a strip of felt that is welted to a timber batten and turned over on to the roof (Figure 6.76). Where there is a parapet wall around the roof the intermediate and top layers of felt are turned up against the wall some 150 mm and covered with a lead sheet flashing which is turned into and wedged in a raked out brick joint.

Because the end laps of rolls of felt are made to overlap down the slope or fall of a roof it is difficult to form cross falls and currents to slopes of roof to a rainwater outlet; therefore, it is usual to drain felt roofing to one continuous verge gutter. Where a built-up bitumen felt covering is laid to falls to parapet
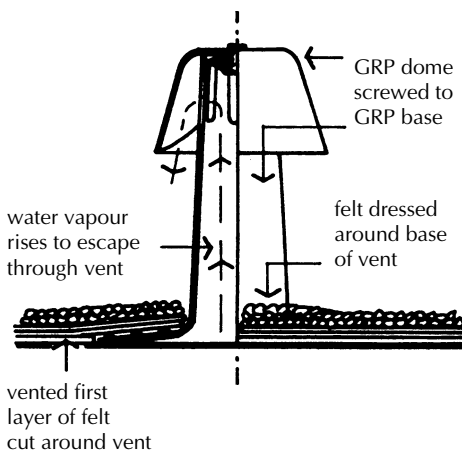
Figure 6.77   Ventilator.

wall outlets it is impossible to avoid an untidy build up of overlaps at oblique cuts of felt.

The usual method of providing ventilation for moisture vapour pressure is plastic ventilators that are fixed behind the felt upstand to parapet walls and to the felt overlap at verges. The parapet ventilators are covered with the apron flashing. On larger roofs, where it is deemed necessary to provide additional ventilators in the surface of the roof, glass fibre reinforced plastic vents are fixed in the roof at about 6 m centres. These ventilators are fixed to the roof and the intermediate and top layers of felt are cut and bitumen bonded around the vents (Figure 6.77).

6.9 Thermal insulation to flat roofs

Most of the materials used in the construction of flat roofs, separately or together, provide insufficient resistance to the transfer of heat to meet the requirement of the Building Regulations. It is necessary, therefore, to build in or fix some material with high resistance to heat transfer to act as a thermal insulation. Current U values for flat roofs should be 0.25 W/m^2 K for flat roof construction (with integral insulation).

Position of the insulation

The most practical position for a layer of insulation for a flat roof is on top of the roof structure either under or over the weathering cover. In this position the insulation boards can be fixed or laid without undue wasteful cutting to provide insulation for the roof structure and utilise the heat store capacity of a concrete roof to provide some heat during periods when the heating is turned off.

As an alternative to fixing insulation on top of a flat roof it may be fixed between the ceiling joists of a timber roof so that the thermal resistance of the timber joists combines with the greater resistance of the insulation material (Figure 6.78). Tables in Approved Document L provide details of the thickness of insulation required for common insulating materials for a range of U values for insulation between joists. The disadvantage of fixing insulation between the joists of timber flat roofs is the wasteful cutting necessary to fit the material between the joists, the labour necessary to support or wedge the material in position and the need to oversize electrical cables (necessary to prevent overheating) that run within the insulation.

The disadvantage of the warm roof is that as the insulation is directly under the roof covering, the material of the covering will suffer very considerable temperature fluctuations between hot sunny days and cold nights, as the roof structure will absorb little if any of the heat or cold to which the roof covering is subjected. These very considerable temperature fluctuations will cause tar and bitumen coverings, such as asphalt and felt, to oxidise more rapidly,

chippings (provides solar reflection and prevents roof membrane lifting in winds)

weather proofing

insulation

vapour control layer (vapour check)

decking

firring (to create fall)

roof joist

plasterboard

A   Warm deck – insulation on top of decking

chippings or concrete paving (prevents uplift)

insulation

weatherproofing

decking

firring (to create fall)

roof joist

plasterboard

B   Inverted roof – insulation on top of weatherproofing

chippings (provides solar reflection and prevents roof membrane lifting in winds)

weather proofing

decking

firring (to create fall)

insulation

plasterboard

at least 50 mm ventilation

C   Cold deck insulation at ceiling level – not recommended (NHBC 2002)

Figure 6.78   Flat roofing configurations.

become brittle and fail and cause severe mechanical strain in other coverings. An inverted or upside down warm roof, with the insulation on top of the roof covering, will protect the roof covering from severe temperature fluctuations.

With the insulation below the roof covering and structure, the roof structure is subject to fluctuations of temperature between hot sunny days and cold nights. Where the insulation is below the roof structure the roof is referred to as a cold roof construction. The disadvantage of cold construction or cold roof is that the moisture vapour pressure of warm inside air may cause vapour to penetrate the insulation and condense to water on the cold side of the insulation, where it may adversely affect the performance of the insulant and on the cold surfaces of the roof structure. Cold roofs are often protected by a vapour check (vapour barrier) on the warm side of the insulation and roofs are ventilated to prevent any build up of moisture.

Avoiding thermal bridges

For efficient insulation against heat loss through the fabric of a building it is necessary to unite the insulation used in walls with that used in roofs and minimise or eliminate those parts of the construction that provide a low resistance path to transfer of heat across thermal bridges (Figure 6.79). The extent to which a detail of construction will act as a thermal bridge will depend on the difference in thermal resistance of the thermal bridge, and that of the adjoining construction. Where the difference is large an appreciable concentration of condensation may appear on the colder surface of the bridge and cause unsightly stains and mould growth and adversely affect materials such as iron and steel.

Where the connection between concrete and masonry components cannot be avoided and a cold bridge occurs, it may be possible to use aerated blocks, which have a high thermal resistance. The blocks are available in a range of 75–355 mm thicknesses. Where the strength of the block is a problem it may be possible to distribute the load over a larger area using a thicker block, so
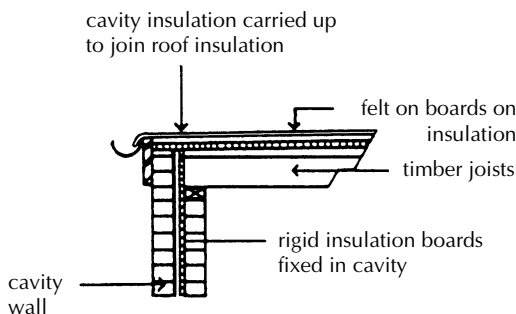
Figure 6.79   Wall insulation joined to roof insulation.
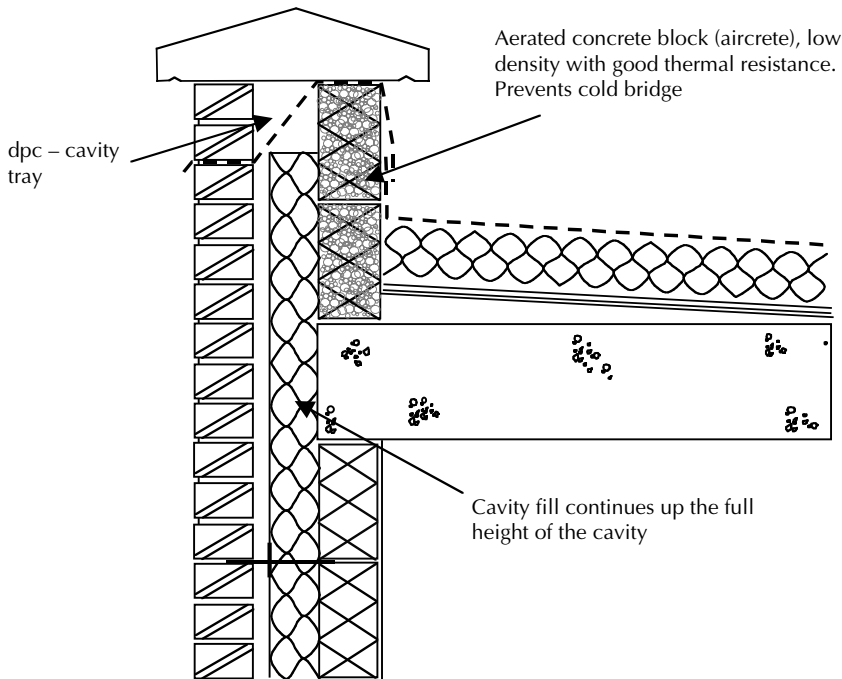
Figure 6.80   Junction with roof and wall.

reducing the load per unit area. Figure 6.80 shows how aerated blocks can be used to prevent thermal bridging above a concrete roof.

In buildings such as offices and places of assembly where the building is intermittently heated with high temperature radiant heaters it is often the practice to fix the insulation to the fabric on the inside face of walls and ceilings in the form of insulation backed plasterboard, as illustrated in Figure 6.81. In this way the radiant heat, when first turned on, immediately heats inside instead of expending some of its energy on heating the fabric.
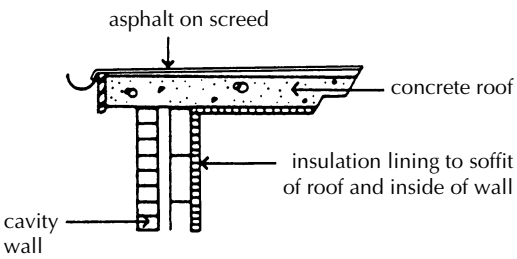
Figure 6.81   Internal insulation.

Insulation materials

To provide the required thermal resistance for a flat roof, one of the semi rigid insulation boards is used for roof level insulation. The cheapest material is mineral wool slabs, either of uniform thickness or cut to provide falls for roof drainage, particularly for asphalt finishes. Expanded and extruded polystyrene boards are the cheapest of the inorganic materials made in boards of uniform thickness or tapered for falls to roofs with expanded polystyrene. The three inorganic material boards PIR, PUR and PUR have the lowest U value. They are the more expensive of the materials and are faced with glass fibre tissue for protection and as a finish impermeable to moisture vapour so that they may be used without the need for a moisture vapour check.

Ventilation

Where there is a likelihood of excessive condensation in roof voids above insulated ceilings, the 'cold roof' space should be ventilated to outside air with a clear air space of at least 50 mm above the insulation to meet the requirements of Approved Document F. This space should be ventilated by continuous strips at least equal to continuous strips 25 mm wide running the full length of eaves on opposite sides of the roof. The ventilating openings are formed in the soffit of the overhang by plastic ventilators fitted with insect screens.

Where the insulation is laid or fixed between the joists there should be a clear space above the top of the insulation and underside of the roof of at least 50 mm for air to circulate across the roof from opposite sides, as illustrated in Figure 6.82. So that electric cables are not run in the insulation, the ceiling is fixed to battens to provide a space in which to run cables.

Where rolls of mineral fibre are laid between joists to the extent that there is not a clear 50 mm space between joists above the insulation, it is necessary to fix timber counter battens across the ceiling joists to provide the recommended 50 mm, minimum ventilation space as illustrated in Figure 6.83.

Figure 6.82   Ventilation.

minimum 50 mm air space above insulation laid between joists

minimum 50 mm air space between counter battens fixed across joists

ventilation openings in two opposite sides of roof with an area at least equivalent to continuous ventilation full length of eaves
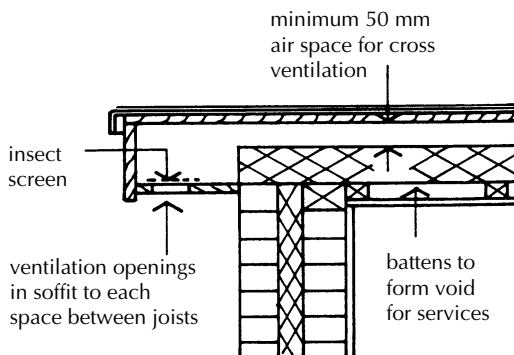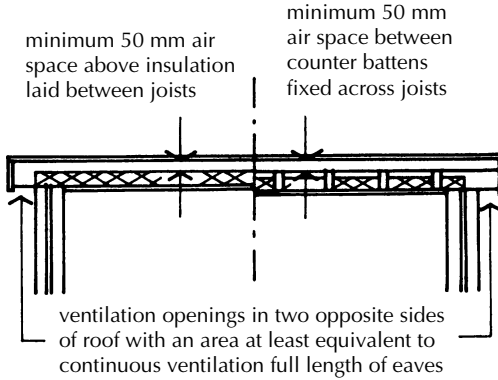
Figure 6.83   Ventilation.

6.10 Parapet walls

External walls of buildings are raised above the level of the roof as parapet walls for the sake of the appearance of the building as a whole. Parapet walls are exposed on all faces to driving rain, wind and frost and are more liable to damage than external walls below eaves level. Because parapet walls are freestanding, their height is limited in relation to their thickness to retain stability. Approved Document A sets limits to the thickness and height of solid parapet walls, as illustrated in Figure 6.84. Where the height (H) of the parapet walls is not more than 600 mm it should be not less than 150 mm thick, where H is 760 mm, the thickness should be not less than 190 mm thick, and where it is not more than 860 mm the thickness should not be less than 215 mm.

Where an external cavity wall is carried up as a parapet wall, as illustrated in Figure 6.85, the limits of height (H) are not more than 600 mm where the

when t = 150
H = 600 max

when t = 190
H = 760 max

when t = 215
H = 860 max

H

t

line of junction of wall and structural roof

T
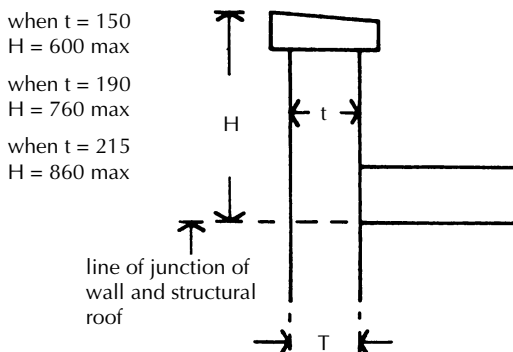
Figure 6.84   Solid parapet wall.

when $t_1 + t_2$ is 200 or less H = 600 max

when $t_1 + t_2$ is more than 200 and equal to or less than 250 H = 860 max

line of junction of wall and structural roof
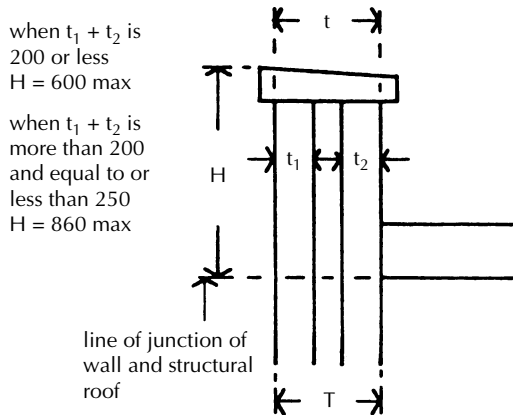
Figure 6.85   Cavity parapet wall.

combined thickness of the two leaves ($t_2 + t_2$) is equal to or less than 200 mm and 860 mm where the combined thickness of the two leaves ($t_2 + t_2$) is greater than 200 mm and equal to or less than 250 mm.

Weather protection

To protect the top surface of a parapet wall, which is exposed directly to rain, it is essential that it should be covered or capped with some dense material to prevent rain saturating the wall. Natural stone was commonly used; termed coping stones, they usually project some 50 mm or more each side of the parapet wall so that rainwater running from them drips clear of the face of the wall. It is practice to cut semi-circular grooves in the underside of the overhang edges of the stones so that water runs off the extreme drip edges of the stones. Featheredge copings are laid so that the weathered top surface slopes towards the roof to minimise staining fair face external brick faces. The stones are bedded in cement mortar on the parapet wall and butt end joints between stones are filled and pointed in cement mortar. For economy, cast stone copings are used instead of natural stone copings. Three common sections employed for coping stones are shown in Figure 6.86.

Coping stones are usually in lengths of 600 mm with the joints between them filled with cement mortar. In time the mortar between the joints may crack and rainwater may penetrate and saturate the parapet wall below. To prevent the possibility of rainwater saturating the parapet through the cracks in coping stones it is common practice to build in a continuous dpc of bituminous felt, copper or lead below the stones (Figure 6.86).

Another method of capping parapet walls is to form a brick on edge and tile creasing capping. This consists of a top course of bricks laid on edge, and two courses of clay creasing tiles laid breaking joint in cement mortar, as illustrated
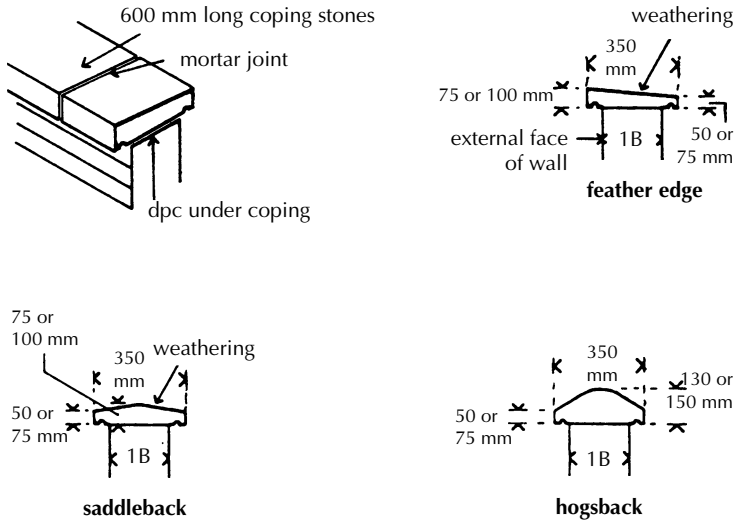
Figure 6.86   Coping stones.

in Figure 6.87. The bricks of the capping are laid on edge, rather than on bed, because many facing bricks have sand faced stretcher and header faces. By laying the bricks on edge only the sanded faces show, whereas if the bricks were laid on bed, the bed face, which is not sanded, would show. Also a brick on edge capping looks better than one laid on bed. Creasing tiles are usually 265 mm long by 165 mm wide and 10 mm thick and laid in two courses breaking joint in cement mortar.

The tiles overhang the wall by 25 mm to throw water away from the parapet below. A weathered fillet of cement and sand is formed on top of the projecting tile edges to assist in throwing water away from the wall. Two courses of good creasing tiles are generally sufficient to prevent water soaking down into the wall and no dpc is usually necessary under them. Parapet walls should be built with engineering bricks or sound facing bricks that are not liable to frost damage and laid in a cement mortar mix 1 part cement to 3 of sand.
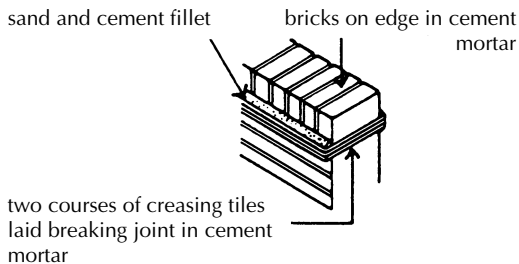
Figure 6.87   Brick capping.
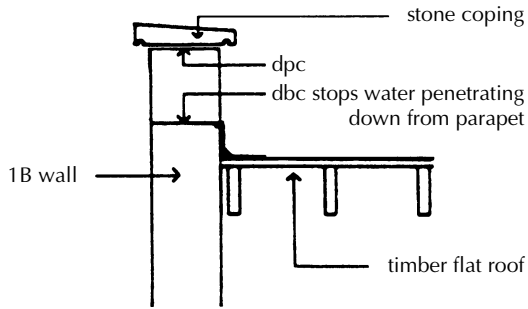
Figure 6.88   Solid parapet.
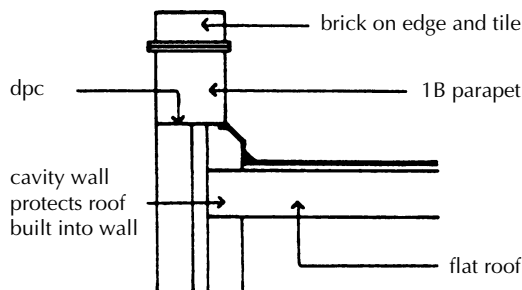
Figure 6.89   Cavity parapet wall.
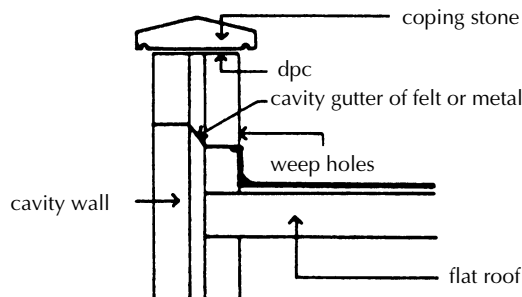
Figure 6.90   Cavity carried above roof.

Parapet wall dpc

It has been practice for some years to form a horizontal dpc in parapet walls at the level of the top of upstand aprons and flashings to flat roof coverings. The purpose of the dpc is to prevent moisture in the exposed parapet wall penetrating down to the roof itself, see Figure 6.88.

To provide protection to the roof structure it is usual to extend a cavity external wall up to the level of the top of the upstand of the roof covering to flat roofs as illustrated in Figure 6.89. In this construction, cavity insulation can be continued up to the level of insulation under roof coverings. A horizontal dpc is usually built in at the level that the solid brick parapet wall is raised on the cavity external wall, as illustrated in Figure 6.89.

A cavity external wall is sometimes continued up as a parapet wall, as illustrated in Figure 6.90. The only advantage of this arrangement is to continue the normal stretcher bond of external brickwork up to the parapet instead of having to change from stretcher to English or Flemish bond in a solid parapet, for the sake of appearance.

As a precaution against water penetrating to the cavity in a parapet wall it is practice to form a cavity dpc and tray which is continued across the cavity and built in one course lower in the roof side, as illustrated in Figure 6.90. To collect and drain any water that may enter the cavity, weep holes are formed with raked out vertical joints in brickwork so that water runs down on to the roof.

7 Windows

A window is an opening formed in a wall or roof to admit daylight through some transparent or translucent material. As the window is part of the wall or roof envelope, it should serve to exclude wind and rain, and act as a barrier to excessive transfer of heat, sound and spread of fire in much the same way that the surrounding wall or roof does.

7.1 Functional requirements

A window is a component part of a wall or roof and therefore it should satisfy the same functional requirements as a wall or roof.

The primary function of a window is to:

❑ Admit daylight and provide an external view

Additional performance requirements include:

❑ Safety – comply with relevant health and safety legislation including the Construction Design and Management (CDM) Regulations
❑ Strength and stability
❑ Resistance to weather – resist water penetration and drafts
❑ Provision of ventilation, including trickle ventilation to prevent condensation
❑ Durability and freedom from maintenance
❑ Fire safety – may also act as fire escape
❑ Thermal performance – as an insulant it should resist the passage of heat and resist thermal bridging
❑ Airtight when closed
❑ Control of daylight (allow light but prevent glare)
❑ Admit or control of solar gain – control heat gain – solar radiation
❑ Acoustics – resistance to the passage of sound
❑ Security
❑ Aesthetics

Daylight

The prime function of a window is to admit adequate daylight for the efficient performance of daytime activities. The quantity of light admitted depends in

general terms on the size of the window or windows in relation to the area of the room lit, and the depth inside the room to which useful light will penetrate depends on the height of the head of windows above floor level. The quantity of daylight in rooms is proportional to the area of glass in windows relative to floor area. The intensity of daylight at a given point diminishes progressively into the depth of the room; the deeper the room the greater the requirement for supplementary artificial light.

Daylight factor

Daylight varies considerably in intensity, both hourly and daily, due to the rotation of the earth and the consequent relative position of the sun, and also due to climatic variations from clear to overcast skies. In order to make a prediction of the relative level of daylight indoors, it is necessary to make an assumption. In Britain and north-west Europe it is current practice to calculate daylight in terms of a 'daylight factor', which is the ratio of internal illumination to the illumination occurring simultaneously out of doors from an unobstructed sky. In the calculation of the daylight factor it is assumed that the illumination from an unobstructed sky, in the latitude of Britain, is 5000 lux and that a daylight factor of 2% means that 2% of the 5000 lux outdoors is available as daylight illumination at a specified point inside.

The assumption of a standard overcast sky (poor outdoor illumination) is taken as a minimum standard on which to make assumptions. The term 'unobstructed sky' defines the illumination available from a hemisphere of sky free of obstructions such as other buildings, trees and variations in ground level, a condition that rarely occurs in practice.

The International Commission on Illumination (CIE) defines daylight factor as 'the ratio of the daylight illumination at a given point on a given plane due to the light received directly or indirectly from a sky of assumed or known luminance distribution, to the illumination on a horizontal plane due to an unobstructed hemisphere of this sky. Direct sunlight is excluded for both values of illumination'. The intensity of illumination or luminance of the standard sky is assumed to be uniform to facilitate calculation of levels of daylight. In practice sky luminance varies, with luminance at the horizon being about one third of that at the sun's zenith (the sun at its highest point). Average daylight factors for various activities are given in Table 7.1.

Where artificial illumination is used to supplement day lighting it is often practice to determine a working level of illumination in values of lux and convert this value to an equivalent daylight factor by dividing the lux value by 50 to give the daylight factor. For example, a lux value of 100 is equivalent to a daylight factor of 2.

In a room with a window on one long side, as illustrated in Figure 7.1, with no external obstructions and a room surface reflectance of 40%, where the glass area is one fifth or 20% of floor area, the average daylight factor will be 4 and the minimum about half that figure. Conversely, to obtain an average

Table 7.1   Recommended average daylight factors.

Building type	Location	Daylight factor
Dwellings	Living rooms Bedrooms Kitchens	1.5 1 2
Work places	Offices Libraries Schools Hospitals Factories	5
All buildings	Residential	2
All buildings	Entrances Public areas Stairs	2

Taken from DD73: 1982.

daylight factor of, say 6, in a room with a floor area of $12\,m^2$, a glass area of about $6 \times 12 \times 5/100 = 3.6\,m^2$ will be required. This method of calculation is generally sufficient when the room is used for general activity purposes such as in living rooms, and it is an adequate base for preliminary assumptions of window to floor area, which can be adjusted later by a more accurate calculation of the light required for activities in which the lighting is critical.

Daylight penetration

A broad measure of the penetration of useful daylight into rooms is, taking an average figure of 7.1 as a daylight factor, where the depth of penetration in line with the centre of the window is equal to the height of the window head above floor level, as illustrated in Figure 7.2. The quantity and quality of daylight illumination in side-lit rooms is affected to an extent by the light reflected from floors, walls and ceilings, which will augment light coming directly through windows. The effect of this reflected light would be affected by the colour
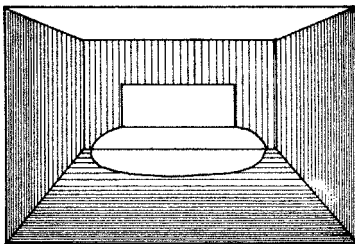
Figure 7.1   Long low window.
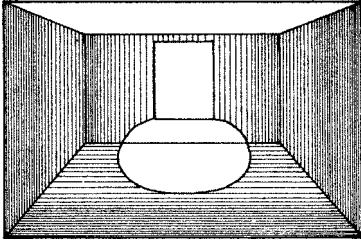
Figure 7.2   Tall narrow window.

and texture of the reflective surfaces. Similarly some daylight, reflected from pavings and nearby external obstructions such as buildings and trees, will add to both the direct penetration of light and internally reflected light.

Reflected light

In the assumption of a daylight factor, account is taken of the contribution of what is termed 'the internally reflected component' and the 'externally reflected component' of indoor daylight illumination. The extent to which both the internal and external reflected light adds to the indoor lighting will be least with low levels of overall daylight and dark, rough textured reflective surfaces, and will be most with higher levels of overall daylight and light coloured, smooth textured reflective surfaces.

The shape, size and position of windows affect the distribution of daylight in rooms and the view out. Tall windows give a better penetration of light than low windows, as illustrated in Figure 7.3. The tall, narrow windows illustrated in Figure 7.3 provide good penetration of daylight into rooms that may be enhanced by the reflection from white painted, internal reveals to the windows. Some distribution of daylight between the windows is provided by the overlap of penetration between the two windows.

Windows in adjacent walls give good penetration and reduce glare by lighting the area of wall surrounding the adjacent window, as illustrated in Figure 7.4. Windows in opposite walls of narrow rooms give good penetration and reduce glare by lighting opposite walls around windows. In the calculation
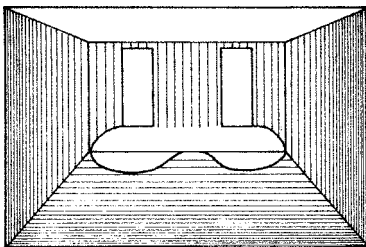
Figure 7.3   Tall narrow windows.
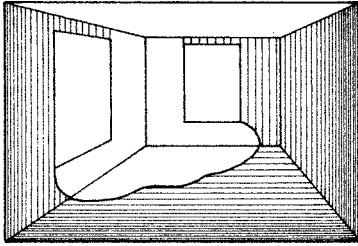
Figure 7.4   Windows in adjacent walls.

of daylight factors it is usual to determine the quantity of daylight falling on a horizontal working plane 850 mm above floor level to correspond with the height of working surfaces such as tables, desks or benches.

Area of glass

The averaged or average daylight factor represents the overall visual impression of the daylighting in a room or space taking into account the distribution of light in the space and the effect of reflected light. The penetration and distribution of daylight in rooms will increase by internal reflection of light from ceilings, walls and floors. For example, in a room 3 m square with a 3 m ceiling height, if the reflectance from light coloured smooth surfaces is good, the net area of glass required to provide a daylight factor of 2, will be 1.28 m as compared with 1.60 m where reflectance is low from dark rough surfaces.

Calculation of daylight factor

Where daylighting by itself or in combination with artificial lighting is critical for the performance of activities, such as drawing at a fixed point or points in a room, it is necessary to estimate the minimum daylighting available at a point. For this purpose there are a number of aids, such as the artificial sky and the overlays for scale drawings. These are described below, although it should be noted that computer software is available to help calculate the daylight factor.

An artificial sky provides luminance comparable to the standard overcast sky, through an artificially lit dome which is laid over a scale model of the building in which photometers are used to measure the light available. The graphical aids in the form of overlays include Waldram diagrams, BRS protractors and the dot or pepper pot diagrams of which the dot diagram is the most straightforward to use. The dots represent a small proportion of the daylight illumination available at that point. The greater the density of dots, the greater the illumination.

The dot or pepper pot diagram

The pepper pot diagram is a transparent overlay on which dots are printed above a horizontal line representing the horizon. The diagram is drawn to a
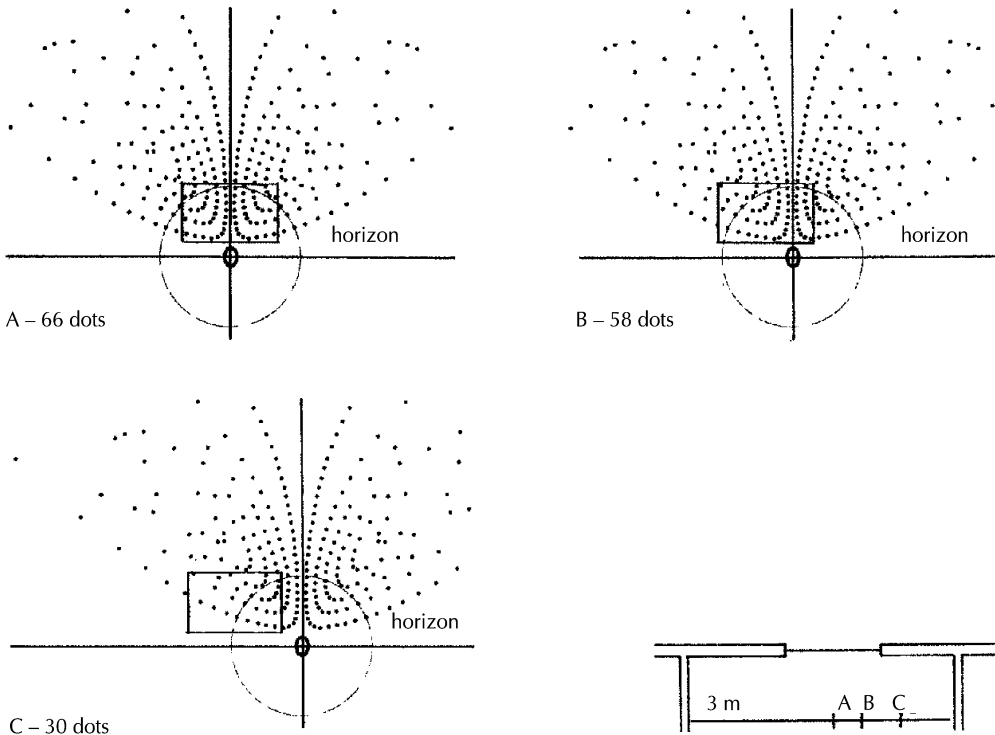
Figure 7.5   Sky component.

scale of 1:100 as an overlay to drawings to the same scale. Each dot represents 0.1% of the sky component. The overlay shown in Figure 7.5 is for daylight through side-lit windows with the CIE standard overcast sky. To use the overlay, draw the outline of a window to a scale of 1:100 so that the outline represents the glass area to scale. The diagram is designed to determine the sky component of daylight on a line 3 m back from the window. Place the overlay on the scale elevation of the window with the horizontal line of the overlay on the line of the working plane (850 mm above the floor), drawn to scale on the window elevation. To determine the sky component at a point 3 m back from the centre of the window, place the vertical line of the overlay on the centre of the window as illustrated in Figure 7.5A, then count the dots inside the window outline. The 66 dots inside the window outline represent a sky component of 66/10, that is 6.6% at a point 3 m back from the centre of the window on the working plane.

To find the sky component on the line 3 m back from the window at other points, slide the overlay horizontally across the window outline until the vertical line of the overlay coincides with the chosen point inside the room, either inside or outside the window outline, as illustrated in Figures 7.5B and C.

40 dots
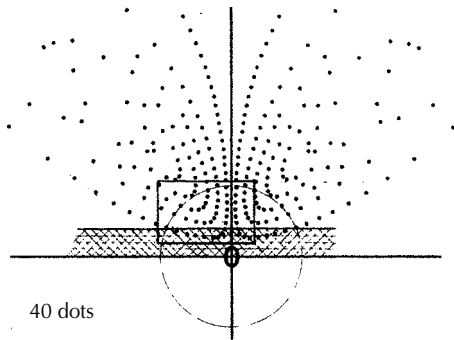
Figure 7.6   Sky component.

Count the dots inside the window outline to determine the sky component at the chosen points.

Where there are obstructions outside windows, such as adjacent buildings, which obscure some of the daylight, the overlay can be used to determine both the loss of light due to the obstruction and the externally reflected component of light due to reflection of light off the obstruction and into the room through the window. A simple example of this is where a long low building will obstruct daylight at a point 3 m inside the room on the centre of the window at the working plane. The outline of the long obstruction is shown in Figure 7.6 by the shaded area. The height of the obstruction above the horizon is represented by the height to distance ratio of the obstruction relative to the point on the working plane inside the window. This ratio is 0.1 for each 3 mm above the horizon on the scale drawing of the window. The number of dots inside the window outline above the shaded obstruction gives the sky component as 40% and the number of dots 12 inside the shaded area, the externally reflected component. These dots represent 0.01% of the externally reflected component.

To find the sky component at points on a line other than the line 3 m back from the window drawn to a scale of 1:100, it is necessary to adjust the scale of the window outline. If the scale of the window is doubled, it will represent the sky component at points 1.5 m back from the window, and if the scale is halved, 6 m back from the window, as illustrated in Figure 7.7 for points on the centre of the window. In adjusting the scale of the window outline it is also necessary to adjust the scale height of the working plane above the floor by doubling or halving the scale as shown in Figure 7.7.

The particular use of this diagram is to test the sky component of daylight inside rooms at an early stage in the design of buildings. By the use of window outlines drawn freehand to scale on graph paper, with the overlay, a comparative assessment of the effect of window size and position on the sky component of daylight inside rooms can quickly be made. This will provide a reasonably
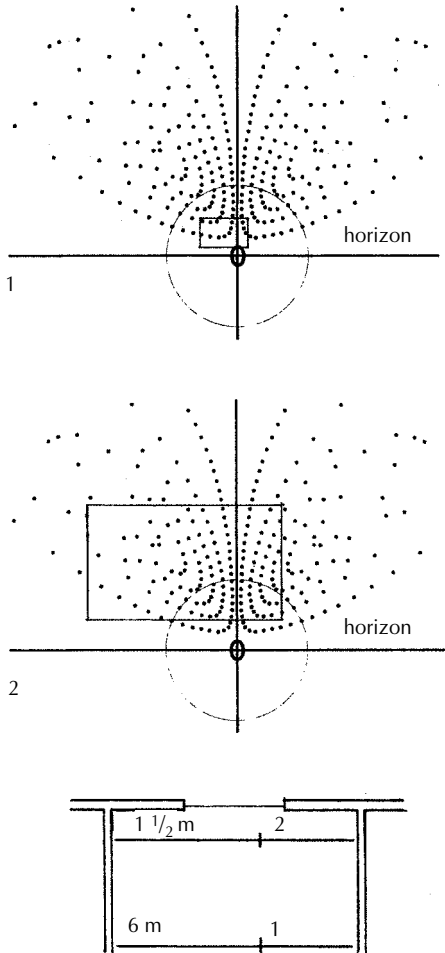
Figure 7.7   Sky component.

accurate assessment of comparative daylight levels in rooms to be used for many activities where the exact level of daylight is not critical.

Quality of daylight

Consideration must also be given to the quality of the light to avoid glare. Glare is defined as 'a condition of vision in which there is discomfort or a reduction in the ability to see significant objects or both, due to an unsuitable distribution or range of luminance, or to extreme contrasts in space or time'. The two distinct aspects of glare are defined as disability glare and discomfort glare.

Disability glare

Disability glare is defined as 'glare which impairs the vision of objects without necessarily causing discomfort', and is caused when a view of bright sky obscures objects close to the source of glare. An example of this is where a lecturer is standing with his back to a window so that he is obscured by the bright sky behind him. Disability glare can be avoided by a sensible arrangement of the position of windows and people, whose vision of objects might otherwise be obscured.

Discomfort glare

Discomfort glare, defined as 'glare which causes discomfort without necessarily impairing the vision of objects', is created by large areas of very bright sky viewed from inside a building which causes distraction, dazzle and even pain. With vertical windows discomfort glare is caused, in the main, by the contrast between visible sky and the room lighting and this contrast can be usefully reduced by splaying window reveals and painting them a light colour to provide a graded contrast between the bright sky and the darker interior. This 'contrast grading' effect can be used with many window shapes and sizes. With very large windows such as the continuous horizontal strip windows which face southwards, discomfort glare is difficult to avoid owing to the large unbroken area of glazing. Here some form of shading device will be required. The degree of glare can be determined numerically and stated in the form of a 'glare index'.

View out and privacy

As well as admitting daylight it is generally accepted that windows perform the useful function of providing a view out and hence a visual link with the outside. Windows also allow a view in, and this may not always be desirable. Depending on the siting of the building and its use, the balance between views out and maintaining privacy will need to be met. Different types of glazing and/or shutters can be used to allow a view out but limit the view in, as can the careful positioning of windows in the building design.

Sunlight

Sunlight causes most coloured materials to fade. It is the ultra-violet radiation in sunlight that has the most pronounced effect on coloured materials by causing the chemical breakdown of the colour in such materials as textiles, paints and plastics by oxidative bleaching. The bleaching effect is more rapid and more noticeable with bright colours. The lining of colour-sensitive curtains on the window side with a neutral coloured material and the use of window blinds are necessary precautions to prolong the life of colour-sensitive materials.

Sun controls and shading devices

The traditional means of controlling the penetration of sunlight to rooms are the slatted wooden louver shutters common to the French window, and awnings and blinds that can be opened or closed. These controls are adjustable between winter and summer conditions, graduated from no shade and the maximum penetration of daylight in winter through some shade and some daylight to full shading in high summer. Fixed projections above windows, such as canopies and balconies, are also used as sun controls to provide shade from summer sun, while allowing penetration of sun at other times of the year. Such fixtures help to control sunlight, glare and solar heat gain.

Solar heat gain

The term 'radiation' describes the transfer of heat from one body through space to another. When radiant energy from the sun passing through a window reaches, for example, a floor, part of the radiant energy is reflected and part is absorbed and converted to heat. The radiant energy reflected from the floor will in part be absorbed by a wall and converted into heat and partly reflected. The heat absorbed by the floor and wall will in turn radiate energy that will be absorbed and converted to heat. In the calculation of energy use in maintaining equable indoor temperature and necessary insulation to limit heat loss, described later, allowance is made for solar heat gain. A calculation is made of the probable solar heat gain as part of the necessary energy input to maintain indoor temperature.

The degree of solar heat gain is affected by the size and orientation of windows. Large windows facing south in the northern hemisphere will be more affected than those facing east or west. The time of year will also have some effect between the more intense summer radiation, which will not penetrate deeply into rooms at midday to the less intense but more deeply penetrating radiation of spring and autumn. Discomfort from solar heat gain has mainly been a consequence of the fashion to use large areas of glass as a sealed walling material for offices and other non-domestic buildings, where the build up of heat can make working conditions uncomfortable. The transmission of solar radiation can be effectively reduced by the use of body tinted, surface modified or surface coated glass.

There are geometric sunpath diagrams that may be used to check whether the face of a building will receive sunlight and when, the depth of penetration and the resultant patch of sunlight on room surfaces and the shading by obstructions at various times of the day throughout the year. An example of the use of 'gnomonic' projections to deduce sunlight patterns on room surfaces throughout the day is shown in Figure 7.8. The diagram shows the floor of a single room with a southeast facing window and the walls on which the sun will shine at half-hourly intervals on 15 January. These sunpath diagrams may also, with suitable overlays, be used to predict the intensities of direct and diffuse solar radiation and the consequent solar heat gain. Computer programs

elevation of
NW wall

9.00
9.30
10.00

9.00   11.00
9.30   11.30
10.00   12.00
10.30   12.30
11.00   13.00
11.30   13.30
12.00
12.30
13.00

elevation of
NE wall

plan of floor
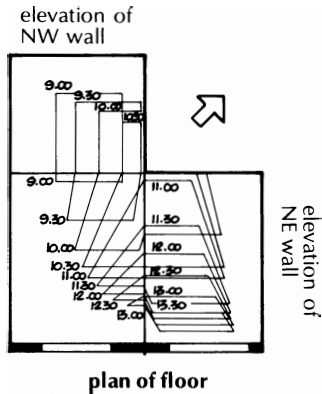
Figure 7.8   Gnomonic projection.

are available that will predict energy consumption for heat loss and heat input calculations and will make allowances for the variable of solar heat gain through windows so that modifications in both window sizes and the heat input from heating plant can be adjusted at the design stage.

Strength and stability

A window should be strong enough when closed to resist the likely pressures and suctions due to wind, and when open be strong and stiff enough to resist the effect of gale force winds on opening lights. A window should also have sufficient strength and stiffness against pressures and knocks due to normal use and appear to be safe, particularly to occupants in high buildings. A window should be securely fixed in the wall opening for security and weather tightness.

Wind loading

To determine probable wind loads on buildings, the method given in BS 6262 can be used for buildings that are of simple rectangular shape and up to 10 m high from eaves to ground level. The basic wind speed is determined from the map of the United Kingdom (Figure 7.9). The basic wind speed is then multiplied by a correction factor that takes account of the shelter afforded by obstructions and ground roughness as set out in Table 7.2 to arrive at a design wind speed. The left-hand column in Table 7.2, 'Height above ground', relates to height of window above ground as plainly the higher above ground, the less will ground roughness and obstructions provide shelter. The four categories of protection by obstructions and ground roughness run from 1 with effectively no protection in open country to 4 with maximum protection from surrounding buildings in city centres. A degree of judgement is necessary in selecting the correction category suited to the site of a particular building as the purpose is to select a window construction suited to the most adverse conditions that

Table 7.2   Correction factors for ground roughness and height above ground.

Height above ground (m)	Category 1	Category 2	Category 3	Category 4
3 or less	0.83	0.72	0.64	0.56
5	0.88	0.79	0.70	0.60
10	1.00	0.93	0.78	0.67

Category 1: Open country; with no obstructions. All coastal areas.
Category 2: Open country; with scattered wind breaks.
Category 3: Country; with many wind breaks; e.g. small towns; city outskirts.
Category 4: Surfaces with large and frequent obstructions; e.g. city centres.
Taken from BS 6262.

Table 7.3   Probable maximum wind loading.

Design wind speed (m/s)	Wind loading (N/m^2)	Design wind speed (m/s)	Wind loading (N/m^2)
28	670	42	1510
30	770	44	1660
32	880	46	1820
34	990	48	1980
36	1110	50	2150
38	1240	52	2320
40	1370		

Taken from BS 6262.

will occur on average once in 50 years. The probable maximum wind loading is then obtained from Table 7.3 by reference to the design wind speed. The wind loading is used to select the test pressure class of window construction necessary and graphs are used to select the required thickness of glass.
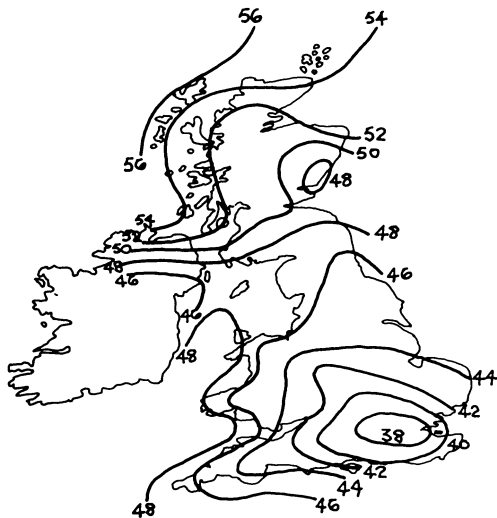
Figure 7.9   Basic wind speeds.

Windows are tested in a laboratory to determine test pressure classes; a sample of manufactured windows complete with opening lights and glass is mounted in a frame to represent the surrounding walls. The criterion of success in the pressure test is that, after the test, the window should show no permanent deformation or other damage and there should be no failure of fastenings.

Air permeability (air tightness)

Air leakage (infiltration) is often found around openings such as windows and roof lights. In a study by Stephen (2000) the air infiltration around windows accounted for 16% of the building's total air leakage. Air leakage around window frames and through glazing joints can be avoided by careful detailing, good construction (workmanship and site supervision) and regular maintenance. The necessary clearance gaps around opening lights can be made reasonably airtight by care in design and the use of weather-stripping, and if necessary injecting expanding polyurethane foam into the joint around the window frame. For comfort in living and working conditions in buildings some regular change of air is necessary. The necessary ventilation should be provided through controlled ventilators, through opening lights, or by mechanical ventilation. It is not satisfactory to rely on leakage of air through windows for ventilation as this leakage cannot be controlled, and it may be excessive for ventilation and conservation of heat or too little for ventilation.

Air leakage

Close attention should therefore be paid to the solid filling or sealing of all potential construction gaps and cracks as well as controlling leakage between window frame and wall. The flow of air through windows is caused by changes in pressure and suction. To control this air movement systems of check rebates and weather-stripping are used in windows, as illustrated in Figure 7.10. The performance of windows with regard to air tightness is based on predicted internal and external pressure coefficients, which depend on the height and plan of the building. These are related to the design wind pressure, which is determined from the exposure of the window and basic wind speed from the map in Figure 7.9. From these, test pressure classes are established for use in the tests for air permeability and water tightness to set performance grades.

Water tightness

Penetration of rain through cracks around opening lights, frames or glass occurs when rain is driven on to vertical windows by wind, so that the more the window is exposed to driving rain, the greater the likelihood of rain penetration. Because of the smooth, impermeable surface of glass, rain will be driven down, across and up the surface of glass thus making seals around glass and clearance gaps around opening lights vulnerable to rain penetration.

Tests for water tightness of windows are based on predictions similar to those used for air infiltration in determining design wind speed, exposure

Any gaps around the perimeter of the window are filled with expanding polyurethane foam. Once set, the foam will be trimmed away and a silicon sealant will provide a neat watertight finish.

Polyurethane foam fills gap between window frame and wall

dpc tray over stone work, once the brickwork is finished the excess dpc will be trimmed off

Horizontal dpc tray under window

Trickle ventilation gap

Polyurethane foam fills the gap all the way through the window frame

Photograph 7.1   Sealing the gap between window frame and wall.

weather strip
in rebate
in frame
behind
drain
channel

lipped
edge of
casement
as check
rebate
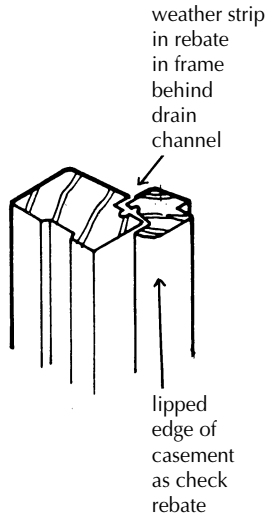
Figure 7.10   Weatherstrip and check rebates.

grades and test pressure classes to set performance standards. To minimise the penetration of driven rain through windows, it is advantageous to:

❑ Set the face of the window back from the wall face so that the projecting head and jamb will to some extent give protection by dispersing rain.
❑ Ensure that external horizontal surfaces below openings are as few and as narrow as practicable to avoid water being driven into the gaps.
❑ Ensure that there are no open gaps around opening lights by the use of lapped and rebated joints and that where there are narrow joints that may act as capillary paths there are capillary grooves.
❑ Restrict air penetration by means of weather-stripping on the room side of the window. If weather-stripping is not used pressure differences may drive water into the joint.
❑ Ensure that any water entering the joints is drained to the outside of the window by open drainage channels that run to the outside.

In modern window design weather-stripping is used on the room side of the gaps around opening lights to exclude wind and reduce air filtration, and rebates and drain channels are used on the outside to exclude rain as illustrated in Figure 7.11.

Fire safety

Approved Document B is concerned with the escape of people from buildings after the outbreak of fire rather than the protection of the building and its contents. The requirement in the Regulations that concerns windows is external
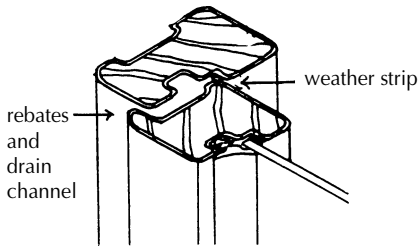
Figure 7.11   Drainage channel.

fire spread. To limit the spread of fire between buildings, limits to the area of 'unprotected areas' in walls and finishes to roofs, close to boundaries, are imposed by the Building Regulations. The term 'unprotected area' is used to include those parts of external walls that may contribute to the spread of fire between buildings. Windows are unprotected areas, as glass offers negligible resistance to the spread of fire. In Approved Document B rules are set out that give practical guidance to meeting the requirements of the Building Regulations in regard to minimum distances of walls from boundaries and maximum unprotected areas.

Ventilation

Windows are usually designed to provide ventilation to rooms through one or more parts that open, encouraging an exchange of air between inside and outside. However, ventilation can also be provided through openings in walls and roofs that are either separate from windows or linked to them to perform the separate function of ventilation. The advantage of separating the functions of daylighting and ventilation is that windows may be made more effectively wind and weather tight and ventilation can be more accurately controlled. This may be an important consideration with regard to safety and security.

The move towards conservation of energy has led to the installation of double and triple glazing to windows in both new and existing buildings and the fitting of effective weather-stripping around the opening parts of windows and doors to reduce draughts of cold air entering the building. The Building Regulations require means of ventilation to habitable rooms, kitchens, bathrooms and sanitary accommodation to provide air change by natural or mechanical ventilation and also to reduce condensation in rooms.

Air changes

The number of air changes will depend on the activities and number of people in the room. The rate of change of air may be given as air changes per hour, for example one per hour for living and up to four for work places, or as litres

side hung

horizontally
pivoted

bottom hung
opening in

vertically
pivoted

vertically
sliding

top hung
opening out
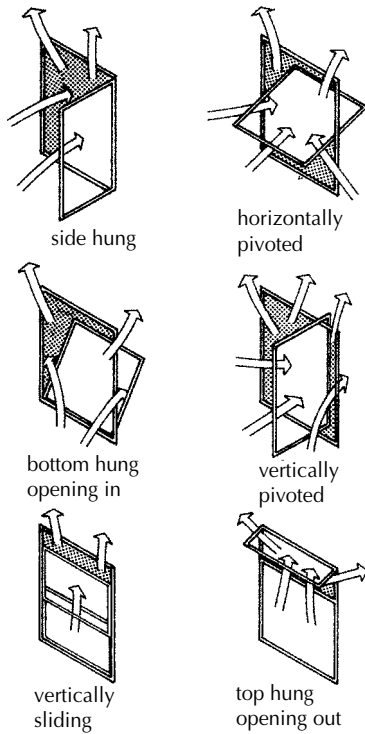
Figure 7.12   Ventilation.

per second as a more exact requirement where mechanical ventilation is used, since it gives a clear indication of the size of inlets, extracts, ducts and pressures required.

The rate of exchange of air will depend on variations between inside and outside pressure and heat, and the size and position of other openings in the room such as doors and open fireplaces that may play a part in air exchange. An open window, by itself, may not thoroughly ventilate a room. For thorough ventilation (complete air change) circulation of air is necessary between the window and one or more openings distant from the window. The probable ventilating action of the various types of window in comparatively still air conditions due to the exchange of warmed inside and cooler outside air is illustrated in Figure 7.12.

Trickle and controlled ventilation in windows
Trickle ventilators can be included in windows either in place of part of the glass or as part of the window head or cill construction, or they may be fixed separate from the windows. For ventilation alone these ventilators need only

permanent ventilation

controlled ventilation
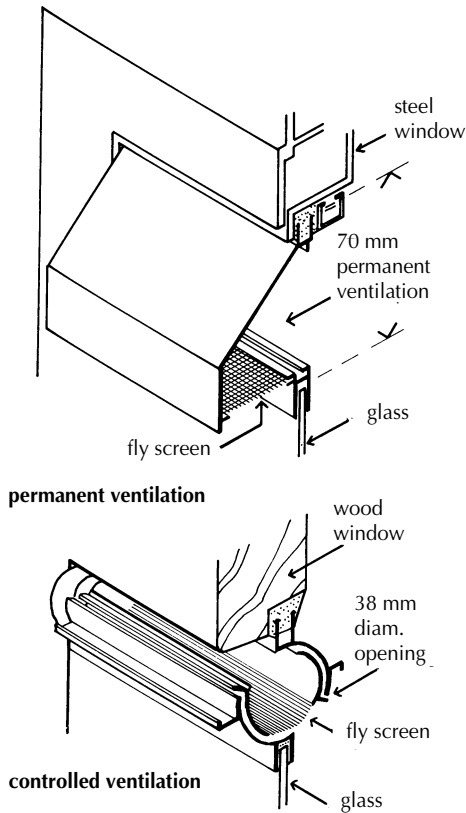
Figure 7.13   Ventilators.

small apertures that can be opened and closed by means of simple manual or automatic controls. The ventilators illustrated in Figure 7.13 are fixed in the rebated glazing opening above the glass. The ventilator shown in the upper diagram is for permanent ventilation and that in the lower diagram for controlled ventilation. Trickle ventilation above windows helps to allow air movement across the face of the glass, thus helping to prevent condensation and allowing water vapour to pass through the ventilator to the outside air.

Approved Document F gives practical guidance to meeting the requirements of the Building Regulations for the provision of means of ventilation for dwellings. The requirements are satisfied for habitable rooms, such as living rooms and bedrooms when there are:

❑ For rapid ventilation – one or more ventilation openings, such as windows, with a total area of at least $\frac{1}{20}$th of the floor area of the room, with some part of the ventilating opening at least 1.75 m above the floor.
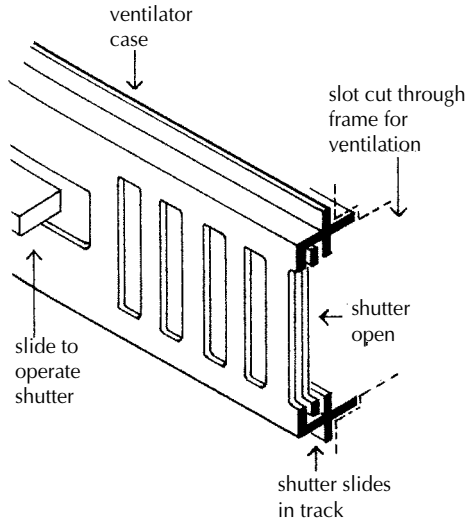
Figure 7.14   Trickle ventilator.

❑ For background ventilation – a ventilation opening or openings having a total area of not less than 4000 mm², which is controllable, secure and located so as to avoid undue draughts, such as the trickle ventilator, illustrated in Figure 7.14.

For kitchens the requirements are satisfied when there is both:

❑ Mechanical extract ventilation for rapid ventilation, rated as capable of extracting at a rate of not less than 60 litres per second (or incorporated within a cooker hood and capable of extracting at 30 litres a second) which may be operated intermittently for instance during cooking, and
❑ Background ventilation, either by a controllable and secure ventilation opening or openings having a total area of not less than 4000 mm², located so as to avoid draughts, such as a trickle ventilator or by the mechanical ventilation being in addition capable of operating continuously at nominally one air change per hour.

For bathrooms the requirements are satisfied by the provision of mechanical extract ventilation capable of extracting at a rate of not less than 15 litres a second, which may be operated intermittently.
   For sanitary accommodation one of the following satisfies the requirements:

❑ Provision for rapid ventilation by one or more ventilation openings with a total area of at least $\frac{1}{20}$th of the floor area of the room and with some part of the ventilation opening at least 1.75 m above the floor level, or

❏ Mechanical extract ventilation, capable of extracting air at a rate of not less than three air changes per hour, which may be operated intermittently with 15 minutes overrun.

Resistance to the passage of heat

A window will affect thermal comfort in two ways: first by transmission (passage) of heat and secondly through the penetration of radiant heat from the sun, which causes 'solar heat gain'. Glass, which forms the major part of a window, offers poor resistance to the passage of heat and readily allows penetration of solar radiation. The transfer of heat through a window is through conduction, convection and radiation. Conduction is the direct transmission of heat through a material, convection the transmission of heat in gases by circulation of the gases, and radiation the transfer of heat from one body of radiant energy through space to another.

U value

The U value of a window depends on the type of glazing and the materials of the window framing. Glass has low insulation and high transmittance values. For example, the U value of a single glazed window of 6 mm thick glass is 5.4 W/m² K and that of a double glazed unit with two 6 mm thick sheets of glass spaced 12 mm apart is 2.8 W/m² K. The overall U value of a window varies to some extent on the materials used in window framing, as wood and uPVC frames tend to provide better insulation against heat transfer than metal. However, advances in window frame technologies now rely on combination of materials to improve thermal performance characteristics.

U value requirements for windows are stated in Approved Document Part L (DTLR, *2001*). Single glazing does not provide a sufficiently low U value, thus double-glazing or triple glazing is necessary. The regulations will be met if the U values do not exceed 2.2 W/m² K, provided that the total area of the windows, roof lights and doors does not exceed 25% of the total floor area. However, a number of low energy houses have been constructed with glazing systems that have a U value of 1.20 W/m² K, also prototype windows have been constructed with U values as low as 0.08 W/m² K (Southwall Technologies, 2002).

Modification of the basic allowance

The basic allowance for the area of windows, 22.5% of the total floor area, may be modified where there is compensating improvement in the average U value of windows. An example of this is where a wood frame window is glazed with a double glazed unit with a 12 mm sealed air gap which is filled with low E (Emissivity) argon gas. Here the U value of the window and frame is taken as 2.2 W/m² K and the modified allowance for the maximum area of the window is 36.5% of the total floor area.
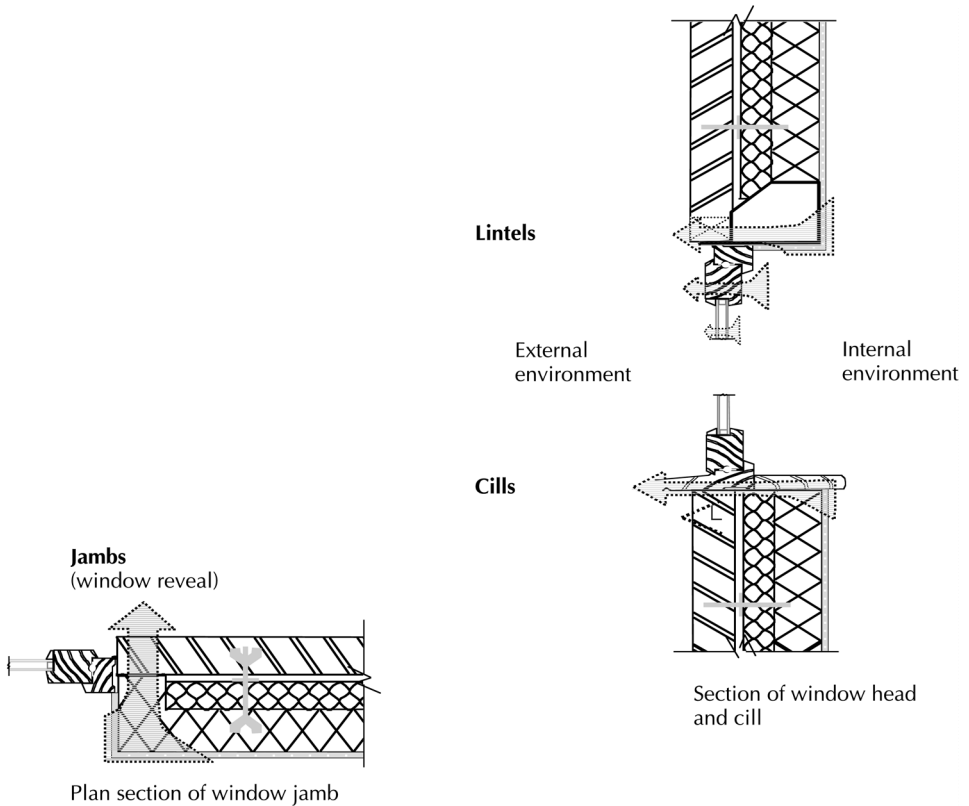
Figure 7.15   Risk of thermal bridging around window and door openings.

Thermal bridging

A thermal bridge is an area of the external building fabric that has a higher thermal transmission than other parts of the building fabric. Thermal bridges lower the overall thermal insulation of the structure and create cold spots where condensation may form. At window openings in walls thermal bridging may occur through:

❑ Most window frames – it is likely to be worse in metal windows than in uPVC or wooden frames, although wooden frames will still provide a thermal bridge
❑ Window and door jambs, lintels and sills (Figures 7.15–7.17)
❑ The edge seal of double or triple glazing units

Positioning of windows – exposure

Depending on level of exposure, the window frame can be installed in different positions to provide additional protection. Exposure to wind and rain

Where there is no thermal break (insulation) at the reveal, heat energy will be conducted out of the building

Typical thermal bridges

❏ Single glazing

❏ Metal window frames

❏ Solid masonry reveals

Thermal bridge

Potential thermal bridging through window and wall jamb

Where the internal environment is humid, condensation may form on cold spots

The cavity in double glazing reduces thermal bridging in windows

Timber and uPVC frames are better insulators than metal

Damp proof course (dpc) backed with 25 mm of insulation along the full length of the window reveal provides a continuous thermal break

Insulation installed at jamb return

Figure 7.16   Prevention of thermal bridging: window jamb detail.

can be reduced by recessing the window from the external face of the wall (Figure 7.18).

Resistance to the passage of sound

Sound is the sensation produced through the ear by vibrations caused by air pressure changes superimposed on the comparatively steady atmospheric pressure. The rate or frequency of the air pressure changes determines the pitch as high pitch to low pitch sounds. The audible frequencies of sound are from

Proprietary insulated cavity closer

Thermal break of insulating foam with sealant pointing

With an insulated plastic (uPVC) proprietary cavity closer the cavity is sealed and does not form a cold bridge.

Thermal break of insulating foam with sealant pointing

Proprietary cavity closer

Insulated to the back of the window or door frame
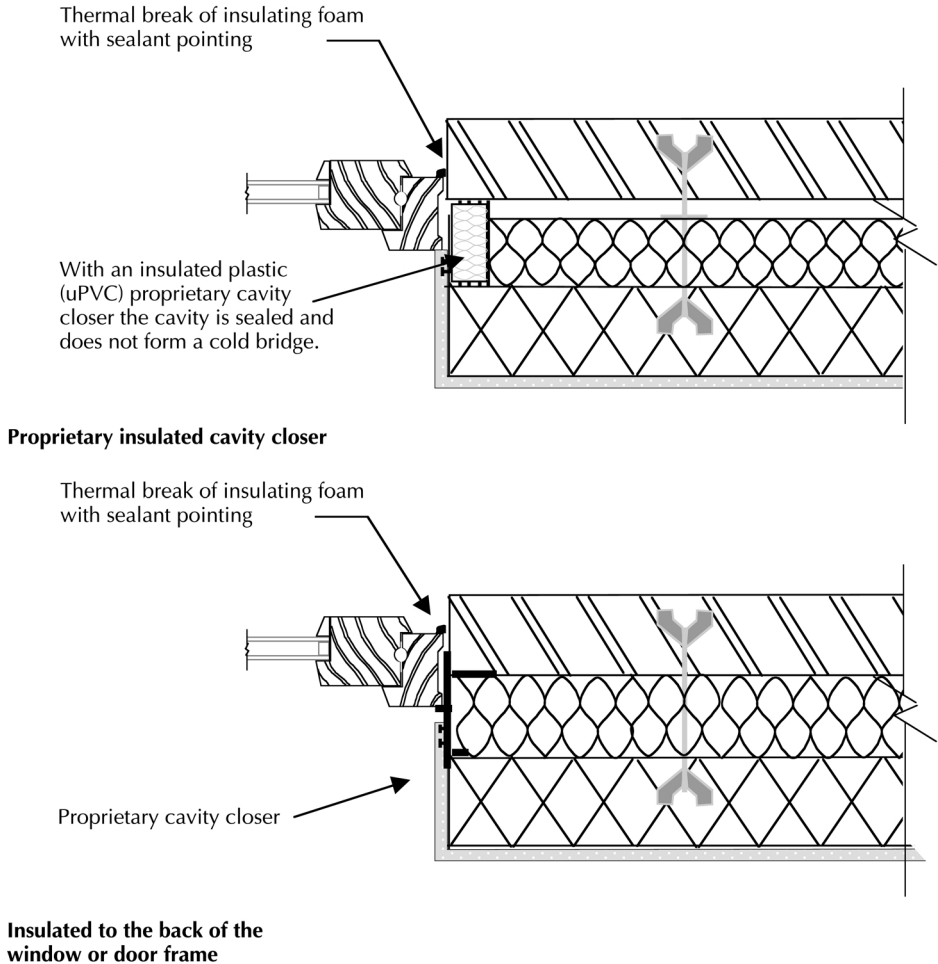
Figure 7.17   Prevention of thermal bridging: window jamb detail.

about 20 Hz (hertz) to 15 000 or 20 000 Hz, one hertz is numerically equal to one cycle per second. The sound pressure required for audibility is generally greater at very low frequencies than at high frequencies.

Because of the variation in the measured sound pressure and that perceived by the ear over the range of audible frequencies, a simple linear scale will not suffice for the measurement of sound. The measurement that is used is based on a logarithmic scale that is adjusted to correspond to the ear's response to sound pressure.

The unit of measurement used for ascribing values to sound levels is the decibel (dB). Table 7.4 gives sound pressure levels in decibels for some typical sounds. Because the sensation of sounds at different frequencies, although

A   Cavity closer and window opening former
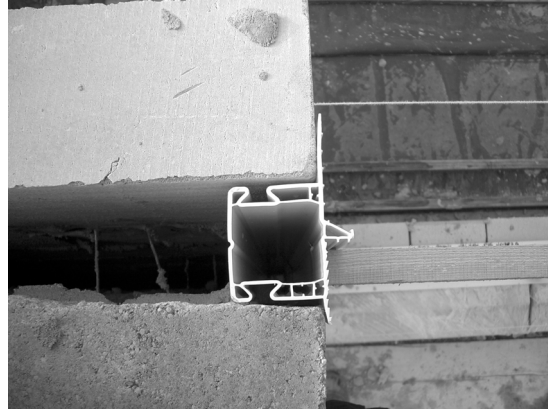
**B   Plan view of un–insulated cavity closer
(also available filled with insulation)**

Photograph 7.2   Cavity closer.

having the same pressure or energy, generally appears to have different loudness, a sound of 100 dB is not twice as loud as one of 50 dB, it is very much louder. The scale of measurement used to correlate to the subjective judgement of loudness, which is particularly suitable for traffic noise, is the A weighting with levels of sound stated in dB(A) units. To provide a measure of generally accepted tolerable levels of audible sound that will not distract attention or be grossly intrusive, tolerance noise levels are set out in Table 7.5.

Airborne sound
Sound is produced when a body vibrates, causes pressure changes in the air around it and these pressure changes are translated through the ear into the sensation of sound. Sound is transmitted to the ear directly by vibrations in air pressure – airborne sound, or partly by vibrations through a solid body that in turn causes vibrations of air that are heard as sound – impact sound. The distinction between airborne and impact sound is made in order to differentiate the paths along which sound travels, so that construction may be designed to interrupt the sound path and so reduce sound levels. Airborne sound is, for example, noise transmitted by air from traffic through an open window into a room and impact sound from a door slamming shut that causes vibrations in a rigid structure that may be heard some distance from the source. The sensation of sound is affected by the general background level of noise to the extent that

Table 7.4   Sound pressure levels for some typical sounds.

Sound	Sound pressure level (dB)
Threshold of hearing	0
Leaves rustling in the wind	10
Whisper or ticking of a watch	30
Inside average house, quiet street	50
A large shop or busy street	70
An underground train	90
A pop group at 1.25 m	110
Threshold of pain	120
A jet engine at 30 m	130

loud noise may be inaudible inside a busy machine shop, while comparatively low levels of sound may be disturbing inside a quiet reading room.

For the majority of people who live and work in built-up areas, the principal sources of noise are external traffic, airborne sound, and internal noise from

Position of window for sheltered / moderate or less severe exposure

Position of window for moderate or less severe exposure

Position of window for severe or very severe exposure

Set flush with wall face   Internal

Set back   Internal

Recessed   Internal

Window within outer leaf of cavity wall

Window set back behind outer leaf

Window rebated within cavity wall. Window in 'check'

Figure 7.18   Exposure to external environment and location of window in external wall. Adapted from BRECSU 1995c.

Table 7.5   Tolerance noise levels

Location	dB(A)
Large rooms for speech such as lecture theatre, conference rooms etc.	30
Bedrooms in urban areas	35
Living rooms in country areas	40
Living rooms in suburban areas	45
Living rooms in busy urban areas	50
School classrooms	45
Private offices	45–50
General offices	55–60

neighbouring radios, televisions, the impact of doors and footsteps on hard surfaces, impact and airborne sounds. Windows (and doors) are a prime source for the entry of airborne sound both through glass, which affords little insulation against sound, and by clearance gaps around opening parts of windows and doors. Reduction of airborne sound can be achieved by weather-stripping around the opening parts of windows and doors.

The transmission of sound through materials depends mainly on their mass; the more dense and heavier the material the more effective it is in reducing sound. The thin material of a single sheet of glass provides poor insulation against airborne sound. A small increase in insulation or sound reduction of glass can be achieved by the use of thicker glass, where an average reduction of 5 dB is obtained by doubling the thickness of the glass. There is no appreciable sound reduction by using the sealed double glazed units that are effective in heat insulation, as the small cavity is of no advantage, so that sealed double glazing is no more effective than the combined thickness of the two sheets of glass. For appreciable reduction in sound transmission, double windows are used where two separate sheets of glass are spaced from 100 to 300 mm apart. An average reduction of 39 dB with 100 mm space and 43 dB with 200 mm space can be obtained with 4 mm glass. This width of air space is more than the usual window section can accommodate and it is necessary to use some form of double window. The double window illustrated in Figure 7.19 comprises two windows, a fixed outer and an inward opening inner window with the glass spaced 50 mm apart. Acoustic lining to the cill, jambs and head between the windows absorbs sound. The hinged inner sash facilitates cleaning glass.

Safety requirements

Two safety requirements from Approved Documents K and N concern the opening parts of windows in buildings other than dwellings. The requirement in Part K is that measures be taken to prevent people, moving in or about the building, from colliding with open windows. This requirement is met where
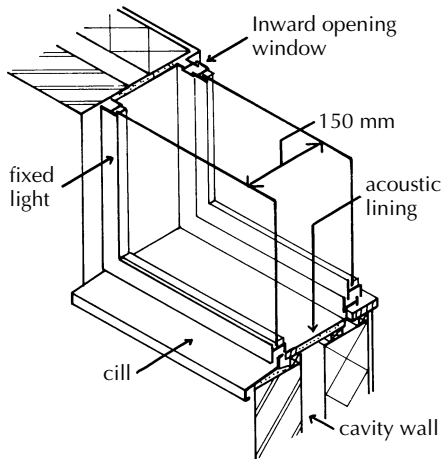
Figure 7.19 Double window for sound insulation.

the projection of a window, either internally or externally, is more than 100 mm horizontally and the lowest part of the projection is more than 2 m above the floor or ground. The requirements in Part N is that windows, skylights and ventilators can be opened, closed or adjusted safely and that there is safe access for cleaning windows. The requirement for access for operating applies to controls that are more than 1.9 m above floor. The requirement for access of cleaning windows, inside and out, where there is a danger of falling more than 2 m, will be met if provision is made for safe means of access. Safety issues relating to glass are discussed later.

Security

Windows and doors are the principal route for illegal entry to buildings. Of the recorded cases of illegal entry, burglary, about 30% involves entry through unlocked doors and windows. Of the remaining 70%, some 20% involves breaking glass to gain entry by opening catches, and the remaining 80% by forcing frames or locks. Window manufacturers and ironmongery suppliers have responded to the increased need for security with product improvements that make unauthorised entry more difficult. Advice is also available from the police through their Secure by Design initiative.

Aesthetics

Windows, along with doors, are an essential element in the appearance of buildings, and therefore their size and shape will also be determined by the designer's aesthetic requirements, which have to be balanced against performance requirements such as thermal insulation, security and maintenance.

Materials and durability

The main materials used for the construction of window frames are timber, metal and plastics. These materials are sometimes used in isolation, e.g. timber window frames and cills, and sometimes in conjunction with other materials, for example PVC windows are usually manufactured with a metal support. The durability of these materials will be determined by the quality of the material, the quality of the applied finish (e.g. paint finish to timber), the detailing of the window and window reveal to protect it from exposure to weather and the amount of maintenance required and manner in which maintenance is implemented. The translucent material most commonly fixed within the frame is glass (see Section 7.4).

7.2 Window types

Terminology

Fixed lights
The term fixed light or dead light is used to describe the whole or part of a window in which glass is fixed so that no part of the glazing can be opened. Typically, fixed lights are one sheet of glass, several sheets of glass in glazing bars, or lead or copper lights glazed (fixed) directly to the window frame.

Opening light
An opening light is the whole or part of a window that can be opened by being hinged or pivoted to the frame or that can slide open inside the frame. Windows with opening lights may be classified according to the manner in which the opening lights are arranged to open inside the frame, as illustrated in Figure 7.20.

Hinged	Side hung
	Top hung
	Bottom hung
Pivoted	Horizontally pivoted
	Vertically pivoted
	Louver
Sliding	Vertically sliding
	Horizontally sliding
Composite action	Side hung projected
	Top hung projected
	Bottom hung projected
	Sliding folding
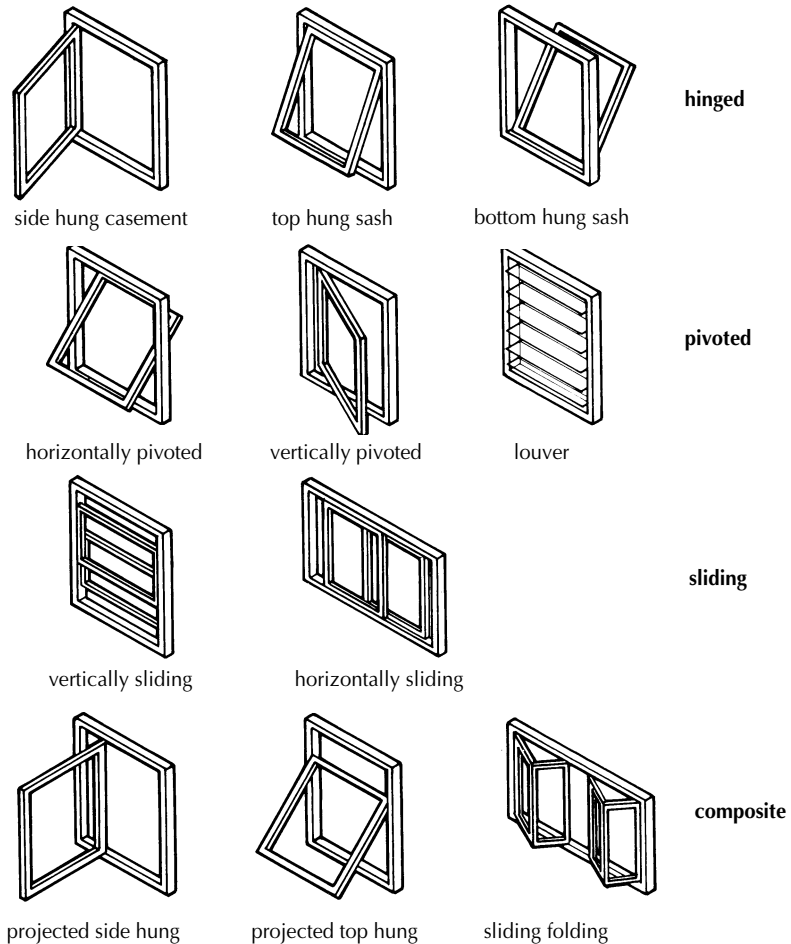
Figure 7.20   Types of opening light.

Hinged opening lights

Side hung

A casement consists of a square or rectangular window frame of wood with the opening light or casement hinged at one side of the frame to open in or out. The side-hung opening part of the window is termed the casement and it consists of glass surrounded and supported by a wooden frame as shown in Figure 7.21, which is an illustration of a simple one-light casement opening out.

The traditional English casement is hinged to open out, primarily because an outward opening casement can be made to exclude wind and rain more easily than one opening inwards. With an outward opening window the casement is
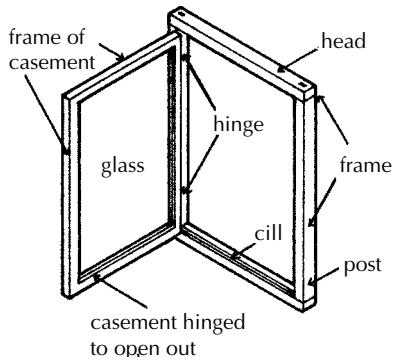
Figure 7.21   Side hung casement window.

forced into the outward facing rebate of the window frame by wind pressure, whereas with an inward opening casement the casement is forced away from the inward facing rebate of the window frame, as illustrated in Figure 7.22, and so acts as a less effective seal against wind and rain. Another advantage of the outward facing casement is that it will not obstruct curtains or blinds when they are drawn together. The French casements, illustrated in Figure 7.23, have been adopted for the warmer climates where the casements may be opened inward and louvers, which are fixed externally, can be closed over the opening to exclude sun and allow some ventilation and provide some security against unwanted entry.

A casement window may be framed with a pair of casements hinged to close together inside the frame as illustrated in Figure 7.24. In the closed position, the rebated vertical stiles of the two casements, which meet at the centre of the window frame, overlap excluding the wind and rain. The advantage of this
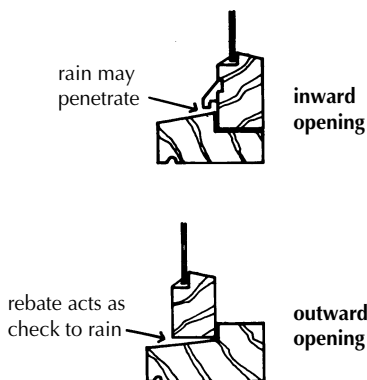
Figure 7.22   Inward and outward opening casements.
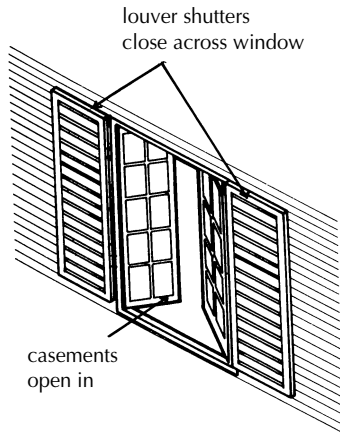
Figure 7.23   French casement.

arrangement is that there is the least width of framing members to obstruct the glazed area.

The disadvantage is that the casements will need top and bottom bolts, in addition to a central catch, to close them firmly into the window frame to exclude wind and rain. Any distortion or slight loss of shape of either one or both of the casements may cause them to bind (stick) inside the frame, making them difficult to open or close. Poorly fitting casements will be ineffective in excluding wind and rain.

A method of framing a two casement window, which is prone to fewer problems, is to use a central member (mullion) so that each casement is hinged to open and close into a separate frame, as illustrated in Figure 7.25. The frame member that separates the casement is termed a mullion. The additional of the mullion slightly reduces the area available for glazing. The advantage of this
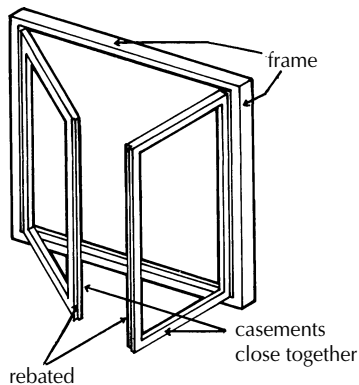
Figure 7.24   Pair of casements.
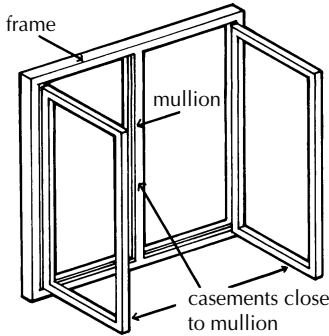
Figure 7.25   Casements and mullion.

arrangement is that distortion of one casement will not affect the closing of the other and that each casement can be adequately secured with a latch to exclude wind and rain.

It has been common to provide small opening lights, called ventlights, which are usually hinged at the top of the widow frame to open out. So that the ventlights can be opened independently of the casements, the window frame is made with a horizontal member, called a transom into which casements and ventlights close (Figure 7.26). Casements with ventlights are usually designed so that the transom is above the average eye level of people using the room, for obvious reasons.

The disadvantages of a casement window are that the casements, ventlights, mullions and transom reduce the possible unobstructed area of glass and therefore daylight and that the many clearance gaps around opening casements and ventlights increase the problem of making the window weathertight.
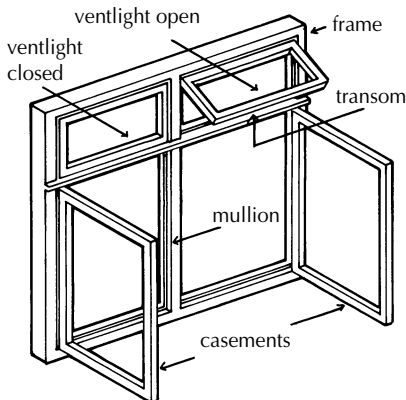
Figure 7.26   Casements and ventlights.

An outward-opening casement may be difficult to clean from inside and is not suited to tall buildings where there is no outside access. The many corners of glass to the comparatively small casements and ventlights make window cleaning laborious such that corners of glass, which are not cleaned, become dirty.

Security
Ventlights that are left open may provide a means of unwanted entry and attention should be given to the size of casement. Small casements may restrict entry, but may still allow someone to reach in and open the catches of larger casements. It is common practice to provide locks on all casements.

Dead lights
The manufacturers of standard casement windows now make a range of windows which provide a large dead light by itself, or a dead light with a casement alongside it and a ventlight above, as illustrated in Figure 7.27. This type of window combines the advantage of a large area of glazing for maximum daylight with the facility for ventilation from a casement or ventlight. The part of a window that cannot be opened is termed a dead light or fixed light.

Top and bottom hung windows
These opening lights are principally used for ventilation, the ventilation being controlled by the degree to which the light is opened. Top hung lights open outwards and bottom hung open inwards, so that the slope of the sash and its glass directs rain outside the building. Usual practice is to position top hung lights at a high level, as in the casement window, to encourage warmed air from inside to escape at the sides of the open sash and cold replacement air to enter below the sash (Figure 7.12). Top hung outward-opening lights are also fixed at high level so that their projection outside is at a high level. Bottom
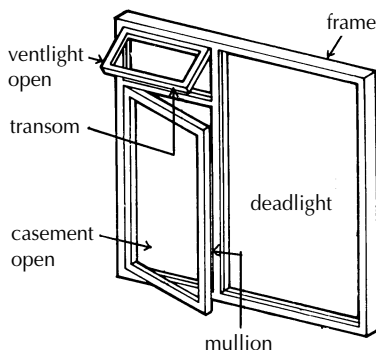
Figure 7.27   Casement window with deadlight.

hung opening-in lights are generally fixed at a low level, so that cold air can enter above the open light and some warmed air from inside can escape at the sides of the sash. Bottom hung opening-in lights are sometimes described as hoppers.

Top hung and bottom hung lights are often used in schools, places of assembly and factories, either opened by hand or by winding gear to control circulation of air between inside and outside. Because they are top or bottom hung these lights must have a positive opening and stay mechanism, otherwise they bang shut or fully open and would be subject to wind pressure. Top or bottom hung opening lights are not so subject to distortion due to their weight as is the side hung casement. While the bottom hung lights may be cleaned both sides from the inside, the top hung lights cannot.

Pivoted opening lights

The width of a casement is limited by the widow frame's ability to support the weight of the casement. The advantage of a pivoted opening light is that the weight of the frame and glass is balanced over the pivots that are fixed centrally. The sashes may be either horizontally or vertically pivoted to open. Horizontally-pivoted sashes are usually pivoted at the centre of the height of the window, as illustrated in Figure 7.28, to balance the weight of the sash over the pivots, and vertically-pivoted to open in by one third of their width to provide least obstruction inside as illustrated in Figure 7.29. Because the weight of the sash is balanced over the pivots, a large sash with small section framing is possible and cleaning the glass on both sides of the window is possible from inside the building. As part of a pivoted sash opens inwards, it may obstruct the movement of curtains. Close control of ventilation with these windows is not possible as they have to open both top and bottom or both sides and they may act like a sail and catch and direct gusts of wind into the building.
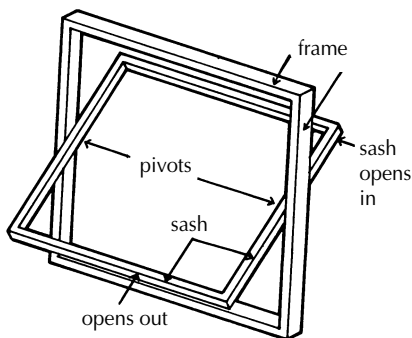
Figure 7.28   Horizontally pivoted sash.
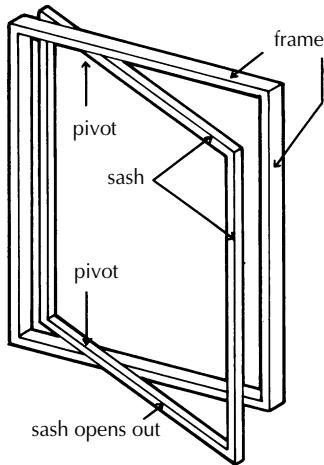
Figure 7.29   Vertically pivoted sash.

An advantage of pivoted windows is that the glass both inside and outside can be cleaned from inside the building. This advantage may be a cause of danger, particularly in tall buildings, where there are no safety stays to horizontally pivoted sashes. It is necessary to ensure that windows can be cleaned safely without the risk of people falling out of the building.

Sliding windows

Vertically sliding sash window
The word casement is properly used to describe the framing material and glass of a side hung window. The frame material for other opening lights is termed a sash. A sash window is shown in Figure 7.30.

The advantage of the vertically sliding sash is that as the weight of the sashes is hung vertically on ropes or chains, the sashes do not tend to distort; in consequence large sashes can be framed from small sections and large unobstructed areas of glass are possible. By setting the bulky box frame of these windows behind a rebate in the surrounding wall, the external appearance of the window is of a large area of glass framed in slim members.

Because of the sliding action, the sashes neither project into or out of the building and close control of ventilation is possible. The sliding action facilitates the use of draught seals between sashes and frame. The disadvantage of this window is that it is not easy to clean the glass on both sides from inside the building. This difficulty has been overcome in recent window design in which it is possible to swing the sashes inwards for cleaning. In time the traditional sash cords will fray and break and it is comparatively laborious to fit new ones. Sashes suspended in spring balances avoid this.
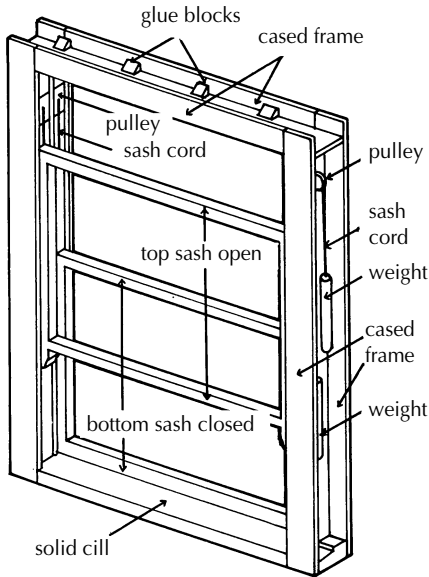
Figure 7.30   Vertically sliding sash window.

Horizontally sliding sash window

The horizontally sliding wood window is illustrated in Figure 7.31. The window comprises two timber-framed sashes that slide horizontally on runners inside a solid timber frame. As there had to be clearance for moving the sashes it is difficult to make this window weathertight and because of the tendency of the sashes to rack, i.e. move out of the vertical, they are liable to jam and can be difficult to open and close. The advantage of this type of window is that there are no internal or external projections from opening sashes and they can be opened to give reasonable control of ventilation. It is difficult to clean the glass both sides from inside.
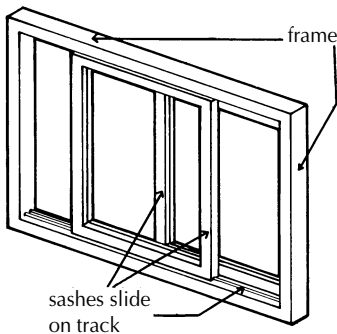
Figure 7.31   Horizontally sliding sash window.

An adaptation of the horizontally sliding window is the 'patio window', which is in effect a combined fully glazed door and window. The large area of glass provides daylight and a full view out. These patio windows or doors are made as two full height sliding sashes or frames, one or both of which slide horizontally on an overhead track from which the sash hangs and slide on guide runners at the bottom. Because of the large area of glass, double or triple glazing units are used to reduce heat loss and weather-stripping is fitted around sashes to exclude wind.

Composite action windows

Composite action windows are designed to act like side-, top- or bottom-hung windows for normal ventilation purposes, by opening on pivots which can be unlocked so that the pivots then slide in grooves in the frame and open on hinged side stays to facilitate cleaning, as illustrated in Figure 7.32. Of the three methods of opening, the top-hung projected window has been the most popular.

Tilt and turn window
This type of window is made specifically for ease of cleaning window glass both sides in safety, from inside the room. For normal operation the sash is bottom-hinged (hung) to open in for ventilation, as illustrated in Figure 7.33. A stay limits the extent to which the head of the sash will open for safety reasons.

safety stay

open to limit   safety stay off
of stay   window
                    open

open fully for
cleaning
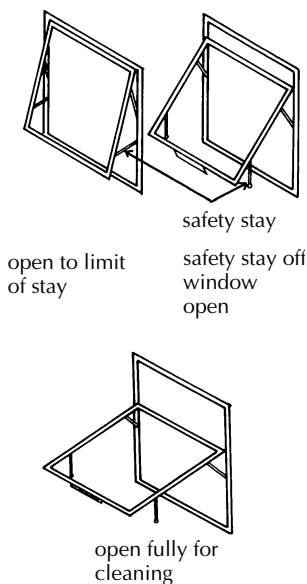
Figure 7.32   Projected top-hung window.
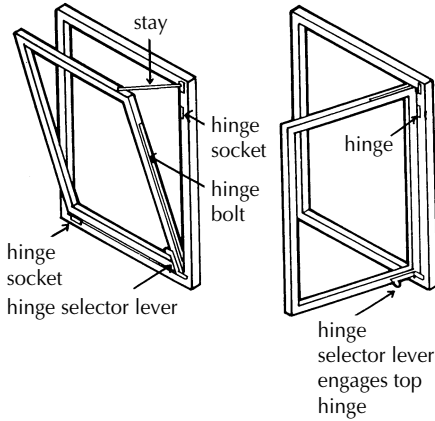
Figure 7.33   Tilt and turn window.

For window cleaning the window can be converted to a side-hung sash when closed. A lever operates to release bolts, which disengage one bottom hinge and simultaneously shoots a side bolt in to engage a top hinge. The sash may then be opened inwards for cleaning the glass on both sides from within.

Sliding folding windows

The sashes in this type of opening window are hinged to each other and fold horizontally in concertina fashion to one or both sides of the window to provide a clear unobstructed opening as illustrated in Figure 7.34. This opening light system is used as either a horizontal window or fully glazed doors where indoor and outdoor areas can be combined. Each glazed sash is hung on a pivoted wheel that runs in an overhead track fixed to the top of the window frame. The lower edge of each sash is fixed to a pivoted wheel that runs in a track to guide the movement of the sash and maintain it in the vertical position.
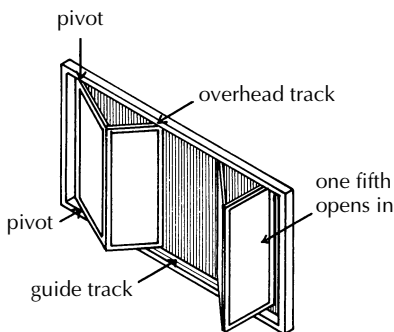
Figure 7.34   Sliding folding sash window.

7.3 Window frames

Their type, e.g. timber, and their construction, e.g. casement, distinguishes window frames. An overview of the main window types commonly used in housing and small-scale developments is provided below.

Timber casement windows

The material traditionally used for windows is wood, which is easy to work by hand or machine and can readily be shaped for rebates, drips, grooves and mouldings. It has a favourable strength to weight ratio, and thermal properties such that the window members do not act as a thermal bridge to heat transfer. The disadvantages of wood are the considerable moisture movement that occurs across the grain with moderate moisture changes, and its liability to rot. The dimensional changes can cause joints to open to admit water, which increases the moisture content that can lead to wet rot. The moisture content of timber at the time of assembly should be 17% or less; the timber should be treated with a preservative, and the assembled window should be protected with paint or stain and maintained on a regular basis. Well manufactured, installed and maintained timber windows are very durable.

Figure 7.35 illustrates the arrangement of the parts of a wood casement window, the members of the frames, casements and ventlights being joined with mortice and tenon joints. The casements and ventlights fit into rebates cut in the members of the frame. These rebates serve as a check to wind and rain in normal positions of exposure.

The traditional joint used in timber windows is the mortice and tenon joint illustrated in Figure 7.36. While traditionally the mortice and tenon was produced by the skilled joiner, woodworking machines are now used to prepare, cut and assemble windows and doors with mortice and tenon or dowel joints.

The casements of mass-produced wood windows are often joined with the combed joint illustrated in Figure 7.37, which consists of interlocking tongues cut on the ends of members which are put together, glued and pinned. With the use of modern glue techniques this joint is as strong as a mortice and tenon joint.

Specifying sizes for hand made and machined windows

It is usual to specify the sizes of timber for joinery for windows, doors and frames as being ex 100×75 mm, for example. The description 'ex' denotes that the member is to be cut from a rough sawn timber size 100×75 mm, which after being planed on all four faces would be about 95×70 mm finished size. This system of specifying the sawn sizes of members is used when joinery is to be prepared by hand operated tools so that the member may be wrought or planed down to a good surface finish without limitation of a precise finished size, yet maintaining the specified size of window. Where joinery is wrought
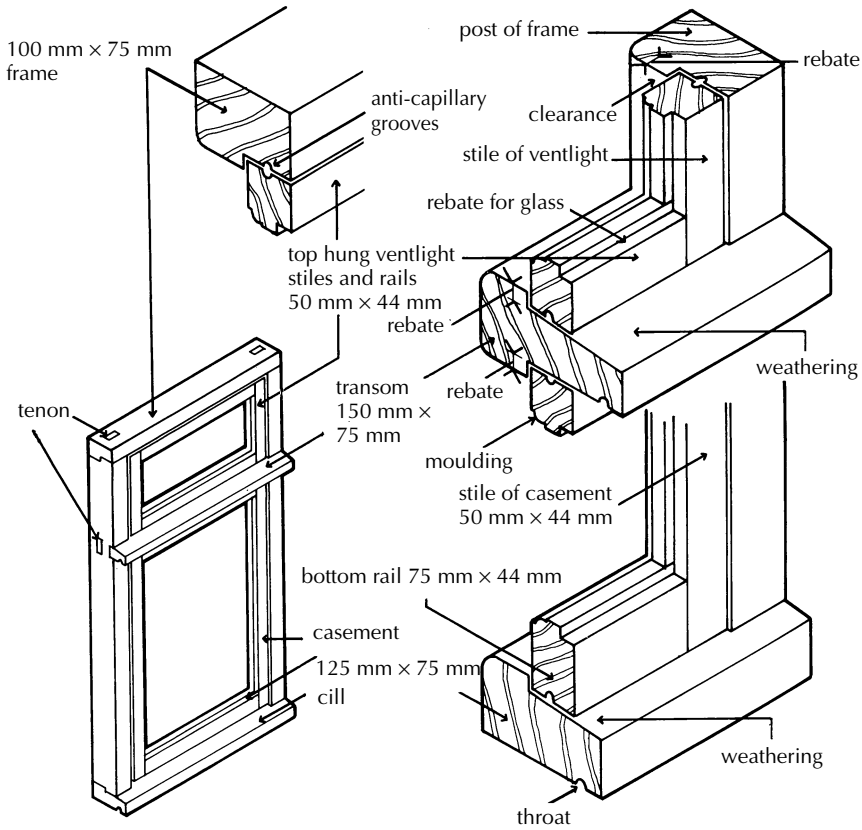
Figure 7.35   Wood casement window.
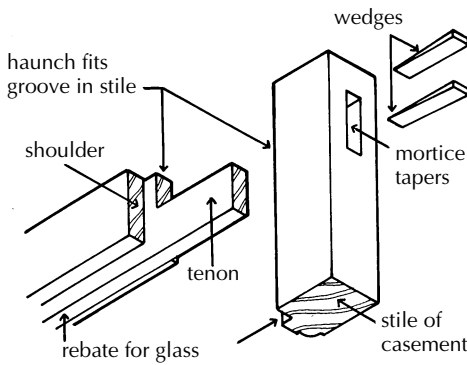
Figure 7.36   Mortice and tenon joint.
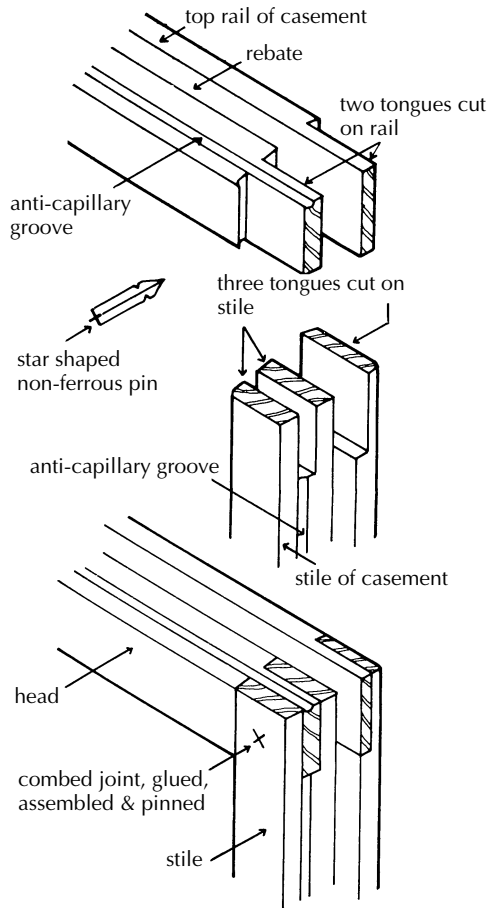
Figure 7.37   Combed joint. Taken apart [top] and assembled [bottom].

or planed by machine it is practice to specify the precise finished size of each member as this is the dimension the operator needs to know when setting up the machine and it is up to them to select the size of sawn timber to be used to produce the finished size.

Casement
A casement is framed from four members, the two vertical stiles and top and bottom rails. Figure 7.38 is an illustration of the framing members of a casement taken apart.

Ventlight
The four members of the ventlight are cut from timbers the same size as the stiles of the casement and are rebated, moulded and joined in the same way as the casement.
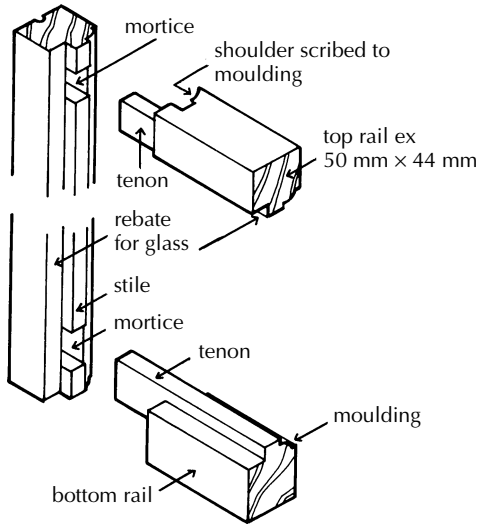
Figure 7.38 Wood casement taken apart.

Window frame

A casement window frame consists of a head, two posts (or jambs) and a cill joined with mortice and tenon joints, together with one or more mullions and a transom, depending on the number of casements and ventlights. The members of the frame are joined with wedged mortice and tenon joints as illustrated in Figure 7.39. The posts (jambs) of the frame are tenoned to the head and cill with the ends of the cill and head projecting some 40 mm or more each side of the frame as horns. These projecting horns can be built into the wall in the jambs of openings or they may be cut off on site if the frame is built in flush with the outside of the wall. The reason for using a haunched tenon joint between posts and head is so that when the horn is cut off there will still be a complete mortice and tenon left.

Standard wood casement

The manufacturers of wood windows produce a range of standard windows. Standard sizes and designs are offered, the advantage being the economy of mass production. In line with the move to dimensionally co-ordinate building components and assemblies, some of the standard ranges of windows are designed to fit basic spaces, with such allowances for tolerances and joints as appropriate. The purpose of dimensional co-ordination is to rationalise the production of building components and assemblies through the standardisation of sizes, within a framework of basic spaces into which the standard components and assemblies may fit.

horn projecting 40 mm or 75 mm

mortice

head of frame

haunch

shoulder

tenon

rebate for
casement

groove

view of wood
casement frame
taken apart

post
of
frame

tenon

mortice

cill

horn
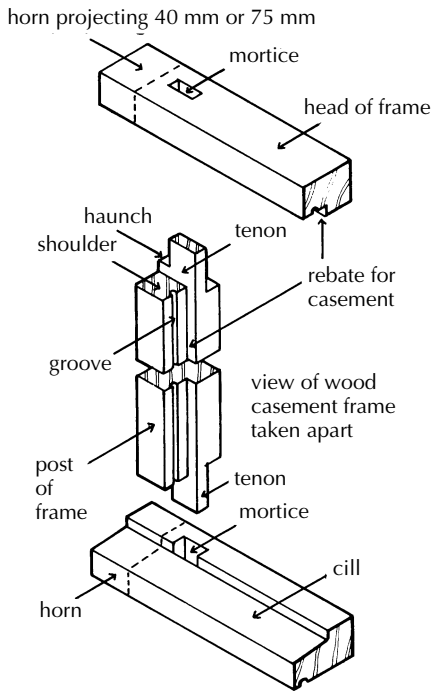
Figure 7.39   Joints of casement window frame.

The casements and ventlights are cut so that their edges lip over the out-side faces of the frame by means of a rebate in their edges, as illustrated in Figure 7.40. These lipped edges are in addition to the rebate in the frame so that there are two checks to the entry of wind and rain between opening lights and the frame. The members of the frame and of the opening lights may be joined with mortice and tenon or combed joints.

Weather-stripping

Building regulations set standards of thermal insulation for the external fab-ric of new buildings, which includes a recommendation to use double and triple glazed windows to conserve energy. The majority of modern windows include systems of weather-stripping around all opening parts of windows to exclude wind, such as those illustrated in Figures 7.41 and 7.42. This weather-stripping serves as an effective seal against the uncontrolled exchange of cold outside and warmed internal air. However, current regulations require some permanent trickle ventilation to prevent condensation forming on windows. In addition to acting as an effective barrier to the entry of draughts of cold air, the systems of weather-stripping also serve as an effective barrier to airborne sound.
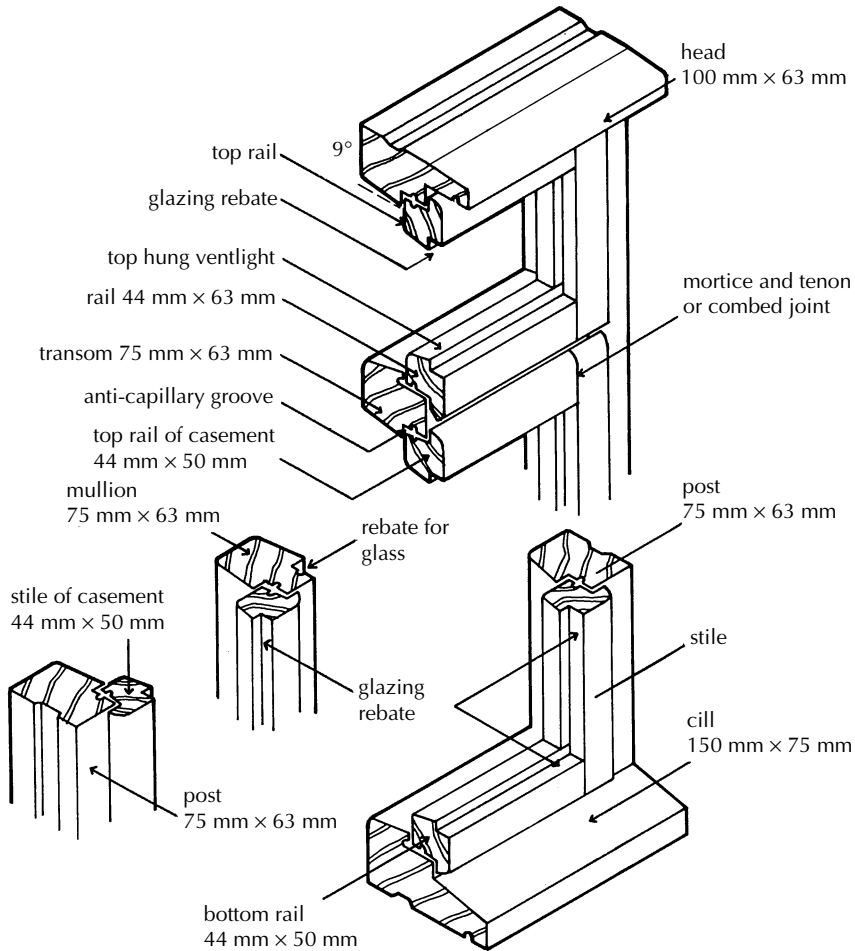
Figure 7.40   Standard wood casement window.

The two forms of weather-stripping that are commonly used are a flexible bulb or strip of rubber, synthetic rubber or plastic that is compressed between the frame and opening light (Figures 7.41 and 7.42) or a strip of nylon filament pile between the frame and opening light (Figure 7.42). For a maximum effect these seals should be fitted or fixed on the back face of the rebate or the inner face of the frame so that the rebate acts as the first defence against wind and driven rain.

The synthetic rubber strips illustrated in Figure 7.41 are tacked inside the rebate of a wood window frame up to the outward facing rebate or may be self-adhesive for fixing to metal or plastic windows. The advantage of these tacked in place or stuck on strips is that they can easily be replaced when they have lost elasticity in use.

rubber self
adhesive strip

rubber strip

EPDM rubber self
adhesive strip

seal fixed in
groove

PVC seal

seal fixed in
groove

tubular strip
of PVC or rubber
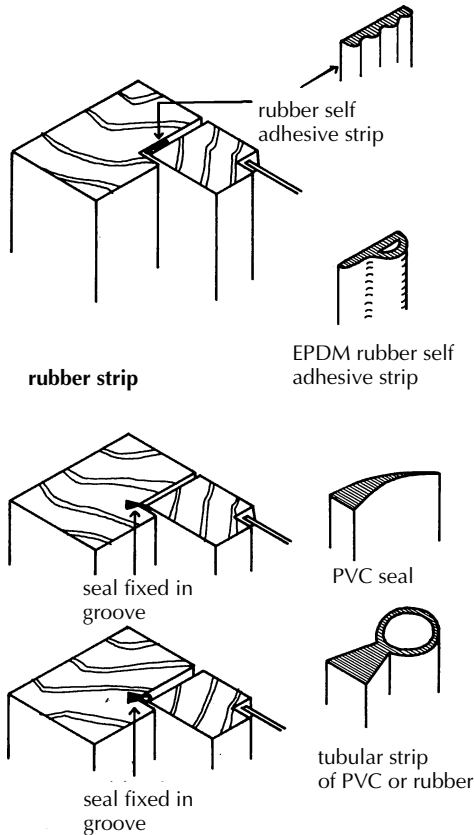
Figure 7.41   Weatherstrips.

The weather strips illustrated in Figure 7.41 are designed specifically to fit
into shallow grooves in wood, metal or plastic windows. The strip is fitted to the
dovetail groove with a machine that forces the end of the strip into the groove to
make a tight fit. Because of the tight fit, these strips are difficult to replace when
they have lost elasticity. The weather-stripping system illustrated in Figure 7.42
consists of an aluminium section into which a strip of nylon filament is fitted.
The aluminium section is tacked or screwed to the wood frame so that the
flexible bulb bears on the sash when closed, as illustrated in Figure 7.42. Both
weather-stripping systems illustrated in Figure 7.42 are supplied mainly for
fixing to existing windows.

Fixing windows
The traditional method of fixing windows in position in a wall is to build solid
walling around them as construction proceeds, thus the window is said to be
'built-in'. The advantages of this are that there is a good fit of the wall to the
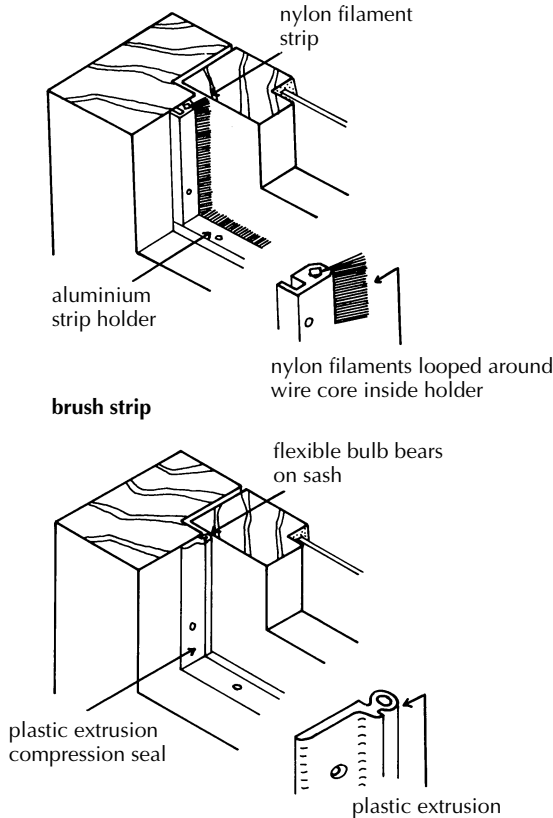
Figure 7.42   Weatherstrips.

window and that secure fixings may be solidly bedded in horizontal courses as the wall is raised (built) around the window. The alternative method is to 'fix-in' (fit) the window after the wall has been built. The wall is constructed leaving an opening with extra clearance for fitting the window in position. To ensure that the opening is the correct size (window plus adequate tolerance for fitting) a timber window profile is used as a temporary guide. The bricklayer constructs the wall around the profile, then the temporary profile is removed and the window fixed toward the end of building operations to avoid damage to the frame and/or glazing.

Softwood window frames can be secured in position in solid walls by means of 'L' shaped galvanised steel cramps or lugs that are screwed to the back of the frame and built into horizontal brick or block courses as the wall is raised. Figure 7.43 is an illustration of a fishtail-ended lug 50×75 mm in size built into a horizontal course of a brick cavity wall. Where the cavity of a wall is continued up to the jambs of a window opening, a system of plastic cavity
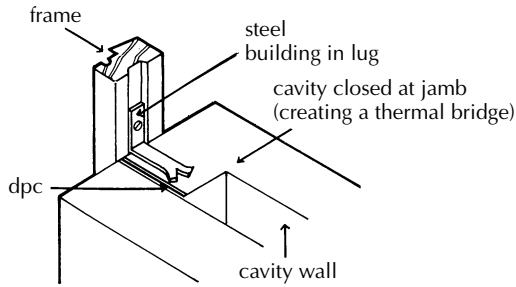
Figure 7.43   Fixing wood window.
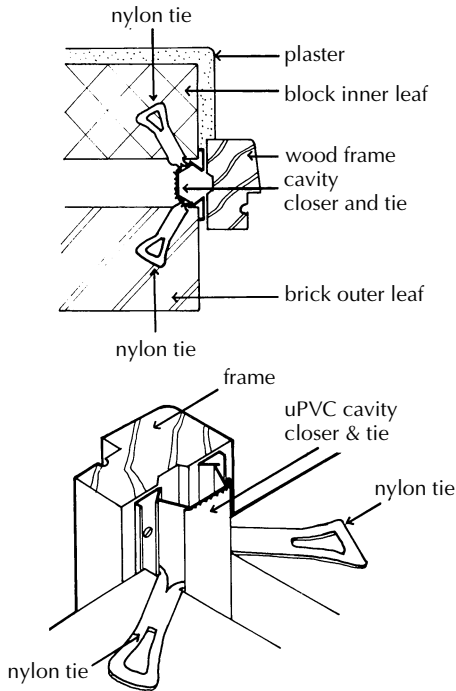
Figure 7.44   uPVC cavity closer and ties.

closers and ties may be used. A preformed uPVC cavity closer can be screwed to the back of the window frame as illustrated in Figure 7.44. Nylon wall ties are slotted into the sides of the cavity closer and built into horizontal courses to secure the frame in place. One cramp, lug or tie is used for each 300 or 450 mm of height of window each side of the frame.

Where frames are fixed-in after the walling is completed, one method of fixing frames is to leave pockets in the jambs of the wall into which lugs can be fitted and the walling then made up. The term 'pocket' is used to describe

A **Temporary window and door template,
used to ensure that the wall opening is built
to the correct size to receive the window and
doorframe.**

B **Alternatively, cavity closer can be
assembled providing a permanent opening
former. The opening formers are held in
place with temporary props.**

Photograph 7.3   Fitting windows: temporary and permanent opening former.

the operation of bedding a few bricks in dry sand so that they may be removed
after the wall is built for the building in of lugs at a later stage. As an alternative,
the window frames may be secured by galvanised iron straps screwed to the
back of the frame and screwed to plugs in the inner reveal of the opening where
they will be hidden by subsequent plastering.

Perimeter sealing to wood windows

The gap between the back of the frame and the surrounding walling is sealed
against weather with one of the elastic sealants described later.

Steel casement windows

Steel casement windows are made either of the standard Z section hot-rolled
steel or the universal section illustrated in Figure 7.45. The casement and frame
sections fit together as illustrated in Figure 7.46, making a reasonably close fit
to exclude rain in all but exposed positions. As an alternative to the standard
Z section the universal or W20 steel section may be used, Figure 7.45B.

There is no straightforward method of overcoming the disadvantage of the
conductivity of steel windows to the transfer of heat and the possibility of some

A. Standard Z section

B. W20 steel window sections
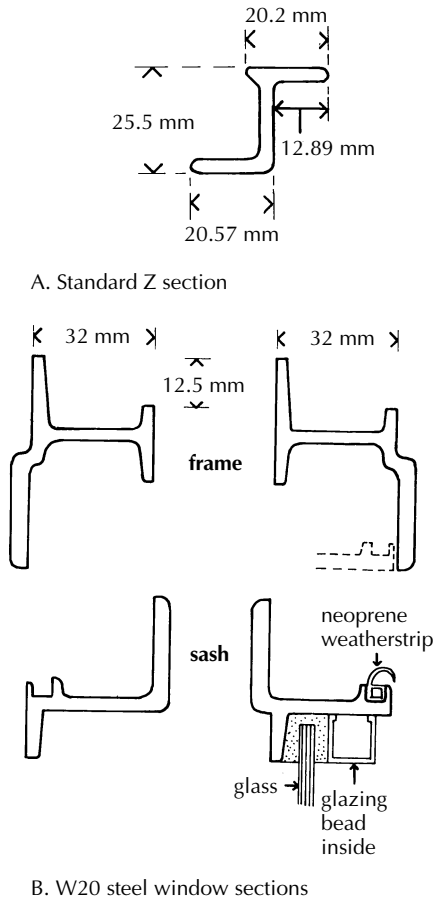
Figure 7.45   Window sections: (A) standard Z section; (B) universal section.

condensation forming on inside faces, particularly in humid atmospheres such as kitchens and bathrooms. Where there is adequate ventilation in kitchens and bathrooms, condensation can be minimised and rust inhibited by sound protective coating.

Steel casement windows are fitted with steel butt hinges or projecting hinges welded to the frame and opening lights. The projecting hinge illustrated in Figure 7.47 is projected outside the face of the window by steel plate brackets and an angle, which are welded to the frame. The pin around which the opening light hinges is offset so that when the casement is open there is a sufficient gap to make it possible to clean the outside of the glass from inside the room. Lever fasteners and peg stays similar to those used for wood windows are welded to the frame and opening lights as illustrated in Figure 7.47.
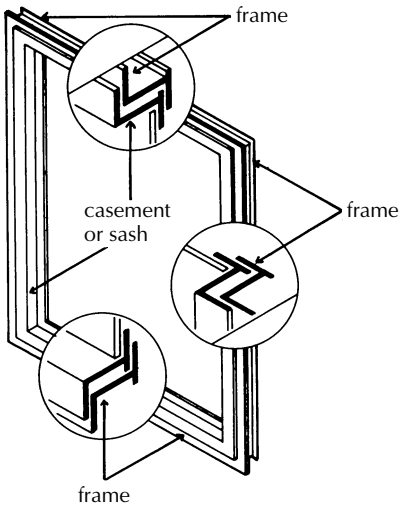
Figure 7.46   Standard metal casement.

Fixing steel windows

Standard steel casement windows are usually built-in to openings in solid walls and secured in position with 'L' shaped lugs that are bolted to the frame as illustrated in Figure 7.48. The lugs are adjustable to suit brickwork courses. Where these steel windows are fixed-in, after walls have been built, a galvanised steel lug is bolted to the back of the frame and its projecting arm is then screwed to a plug in the inner reveal of the wall. These lugs will later be obscured by plaster. Although not common, timber sub-frames have been used too for steel windows (Figure 7.49).
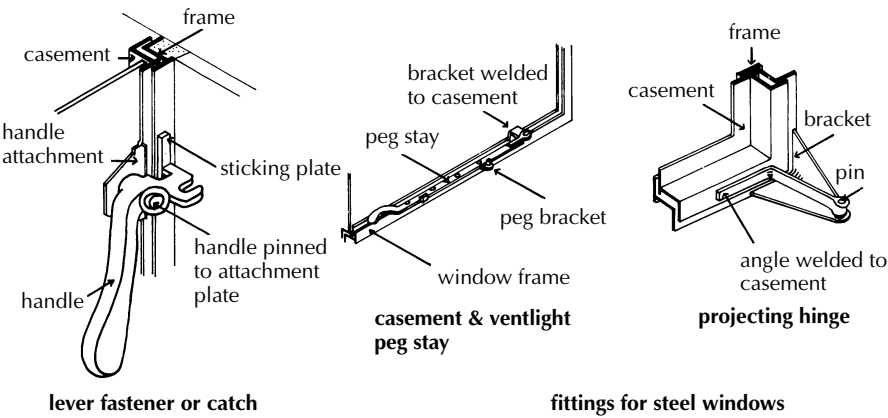
Figure 7.47   Hinges and fasteners.
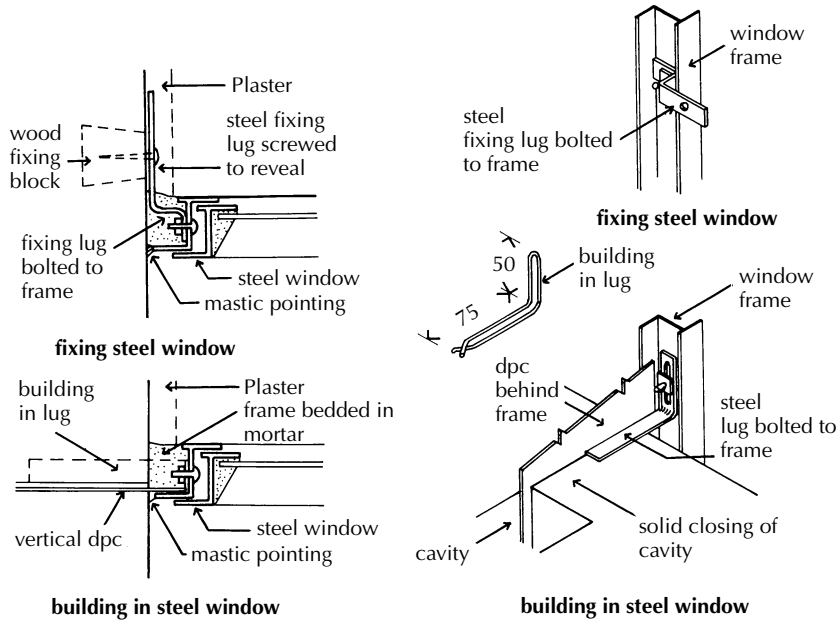
Figure 7.48 Fixing steel windows.

Aluminium casement windows

The majority of aluminium windows that are made today are of sections extruded from aluminium alloy in a wide range of channel and box sections with grooves for lips for weather-stripping and double-glazing. The sections are mitre cut and mechanically cleated or screwed at joints, which are sealed against entry of water as illustrated in Figure 7.50. These thin-walled channel and box sections give the material adequate strength and stiffness for use as window sections. The material can be readily welded and has good resistance to corrosion. On exposure to air aluminium forms an oxide surface coating, which is a coarse textured light grey finish. Because of the unattractive appearance of the natural oxide finish, aluminium window sections are usually finished with anodised, polyester powder or liquid organic coatings as protection against oxidisation and as a decorative coating that can be easily cleaned.

A disadvantage of aluminium as a window material is that it is a good conductor of heat and a potential thermal bridge. Some manufactures have introduced a 'thermal break' illustrated in Figure 7.51. The separate aluminium window sections are mechanically linked to the main window sections through plastic thermal break sections; however, the effectiveness of the small thermal break in reducing heat flow is minimal. The insulating glass (IG) double glazed units are secured with aluminium beads and the window is weather-stripped with preformed synthetic rubber seals. The aluminium frame is secured to
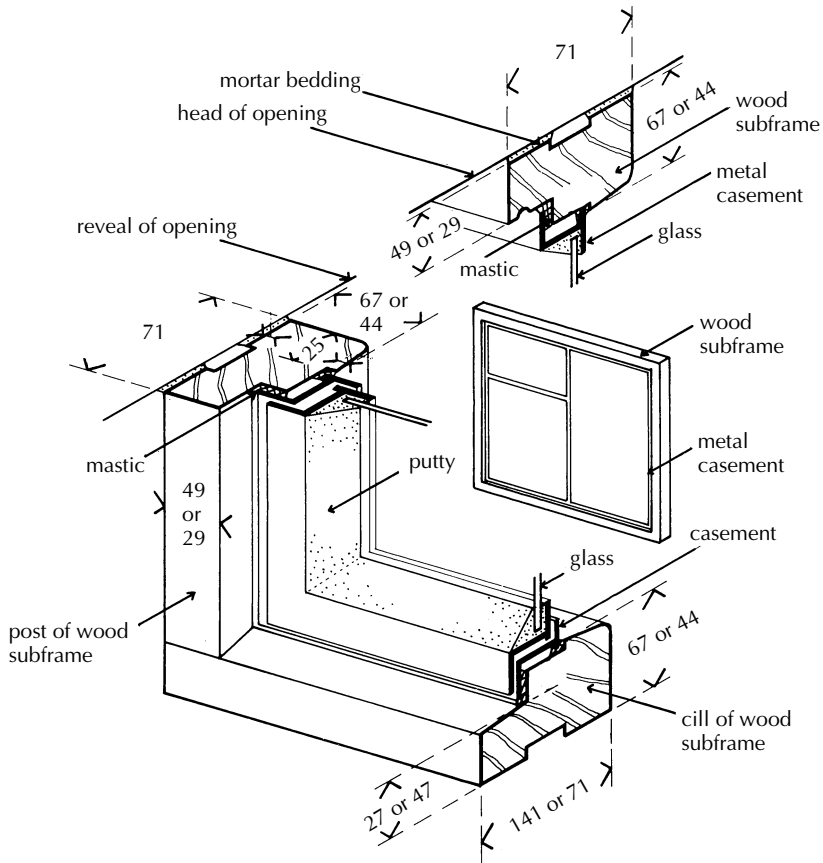
Figure 7.49   Timber sub-frame for metal window.

the surrounding wall by aluminium lugs that clip to the back of the frame at
centres of up to 600 mm and also adjacent to hinges and fasteners, with the
lugs screwed to plugs in the wall.

Sealants

A sealant is a material that is initially sufficiently liquid or plastic for application
and which cures or changes to a material that will adhere to surrounding
surfaces, retain its shape and accommodate some small movement without
loss of seal against wind and rain. Sealants used for sealing perimeter joints
around window frames are classed as plastoelastic, elastoplastic or elastic.

❑ Plastoelastic sealants, which have some elastic property, remain predomi-
   nantly plastic and can be moulded.
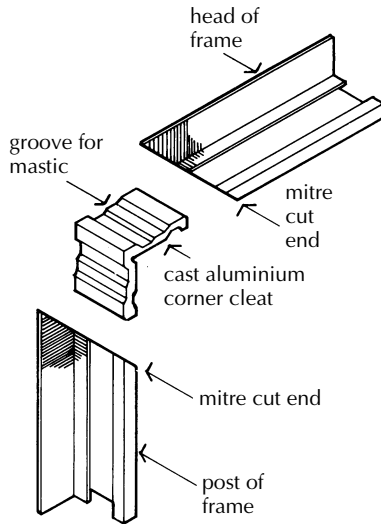
Figure 7.50   Corner cleat for aluminium window.

❑ Elastoplastic sealants, which develop predominantly elastic properties as they cure, will return to their former shape when stress is removed and also retain some plastic property when stressed over long periods.
❑ Elastic sealants will, after curing, have predominantly elastic properties in that they will continue to resume their former shape once stress is removed, during the anticipated useful life of the material.

Acrylic, polysulphide, polyurethane and silicone
The materials that may be used for perimeter sealing around window and door-frames are acrylic, polysulphide, polyurethane and silicone. Of these, acrylic is classed as plastoelastic, polysulphide as elastoplastic and polyurethane and silicone as elastic. In general the plastoelastic material is easier to use because of its predominantly plastic nature, but it will not form as tough and elastic a surface as elastoplastic materials that have some plastic property. The elastic materials need some experience and skill in use for successful application.

One and two part sealants
Polysulphide and polyurethane sealants are produced as either one-part sealants ready to use, or as two-part sealants that have to be mixed before use. The one-part sealants are more straightforward to use as there is no mixing and the material cures or loses plasticity fairly slowly, allowing adequate time for running into joints and compacting by tooling.

The two-part sealants require careful, thorough mixing and, as they cure fairly rapidly, require skill in application. The advantage of the two-part sealants is that as they cure fairly rapidly they are less likely to slump and
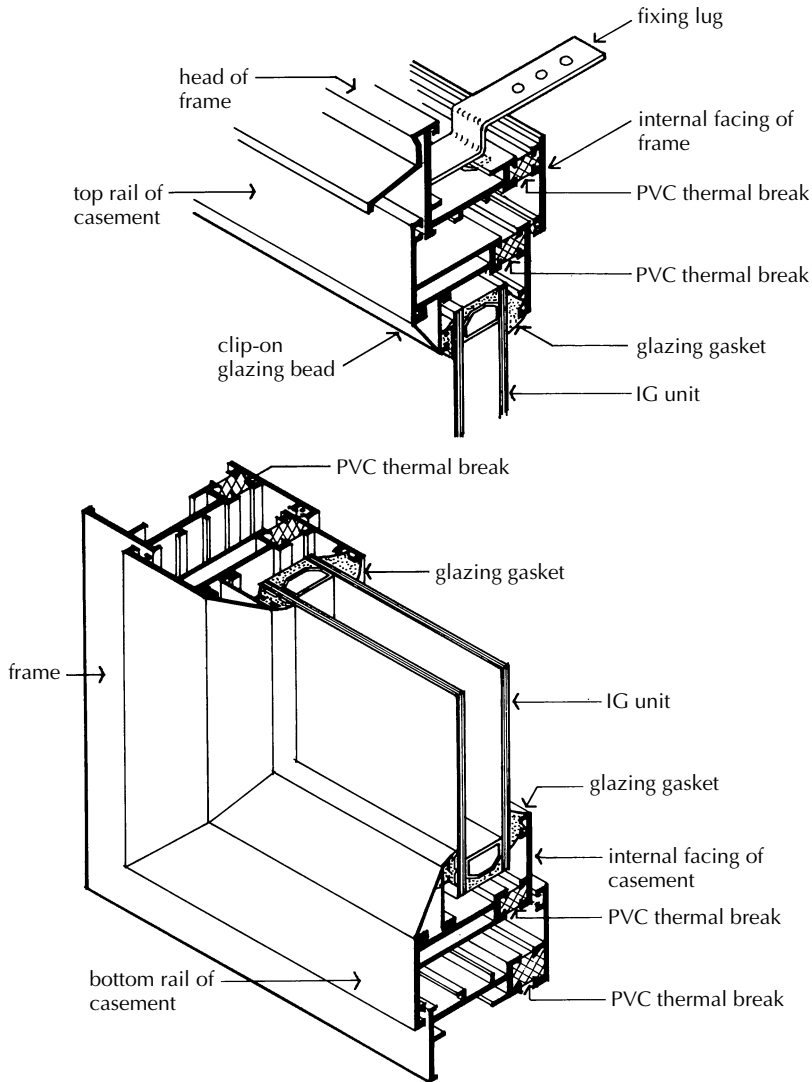
Figure 7.51 Thermal break aluminium casement window.

lose shape and adhesion than the more slow curing one-part silicone sealants which cure fairly rapidly to form a tough, elastic material, require rapid application and tooling for compaction.

Window sealant functions

As the prime function of a sealant to perimeter gaps around window frames in traditional walling is as a filler to exclude wind and rain, it should adhere strongly to enclosing surfaces, be resistant to the scouring action of weather

Sealed window unit

Aluminium window frame

Thermal break

Thermal breaks are introduced into the aluminium window structure to reduce the heat flow across the window frame.
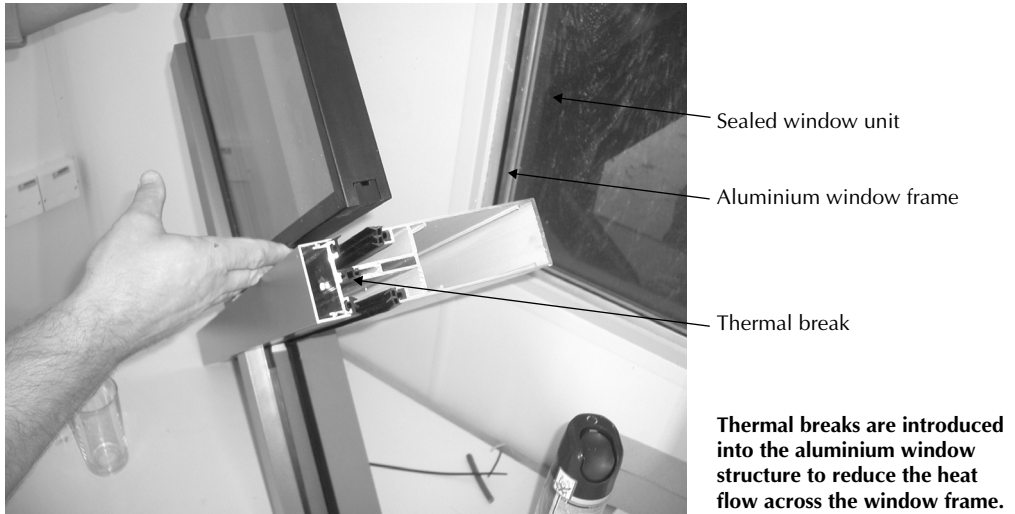
Photograph 7.4   Thermal break in metal window.

and sufficiently elastic to accommodate small thermal movements for the anticipated life of the material. The expected useful life of sealants, after which they should be renewed, is up to 15 years for acrylic and up to 20 years for polysulphide, polyurethane and silicone.

To ensure maximum adhesion, the surfaces on to which a sealant is run should be clean, dry and free from dust, dirt and grease. Sealants are usually run into joints from a gun operated by hand pressure or air pump and, for appearance, the sealant should not be too obvious.

The form of sealant joint used depends on the width of the perimeter gap between window frame and surrounding wall and whether the frame is set in a rebate. The types of joint used are butt joint, lap joint and fillet seal (Figures 7.52–7.54). The butt joint (Figure 7.52) is formed between the back of the frame and the reveal of the opening. Foamed polyethylene is first run into the gap as a backing for the sealant. The sealant is then run into the joint and tooled with a spatula to compact the material and make good adhesion to the two surfaces. It is finished with a slight concave finish up to the edge of the window frame.

The best gap width for the joint is from 6 to 12 mm; this is wide enough for application of the sealant, yet small enough to contain the sealant and not too obvious. Butt joints up to 25 mm are practical with the depth of the sealant being half that of the gap. These wider joints tend to look somewhat unsightly. To prevent the sealant adhering to the outside face of the window frame it is good practice to use masking tape up to the edge of the outside face of the frame. Once the sealant is sufficiently cured the masking tape is stripped towards the sealant. A lap point is formed where the window frame is set behind an accurately formed rebate in wood, metal, masonry or concrete
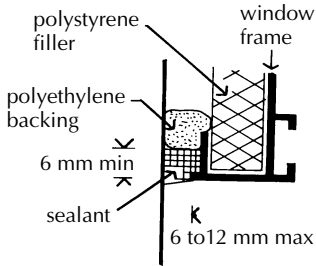
Figure 7.52   Butt joint.
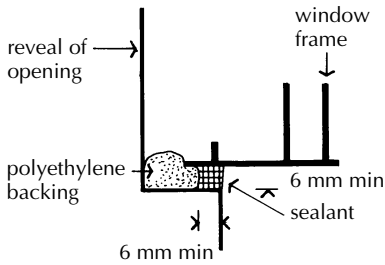
Figure 7.53   Sealed lap joint.

surrounds (Figure 7.53). The sealant is run into the gap over a polyethylene backing and tooled to a slight concave finish to masking tape. It is more difficult to form or renew this joint, which is less obvious than a butt joint.

A gap of less than 6 mm between the window frame and the opening in the wall is too narrow for gunned-in sealant. Here a fillet seal is used, which is formed to adhere to the outside face of the frame and the wall opening (Figure 7.54). The fillet seal is run as a convex fillet to provide sufficient depth of sealant, which is finished as it comes from the gun.
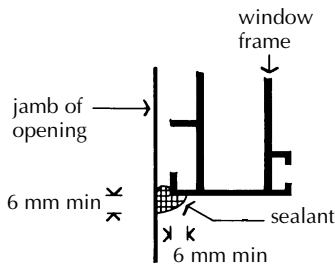
Figure 7.54   Fillet seal.

uPVC casement windows

These windows are fabricated from extruded, high-impact strength, white uPVC (unplasticated polyvinyl chloride). Modifiers, such as acrylic, are added to the PVC material to improve impact strength. Pigment may be added to produce body coloured uPVC. The heated, plastic material is forced through dies from which it extrudes as thin-walled hollow box sections, complete with rebates, grooves and nibs for beads, weather seals, glazing seals and for fixing hardware. The word plastics is used in a general sense to embrace a wide range of semi-synthetic and synthetic materials that soften and become plastic at comparatively low temperatures so that they can be shaped by extrusion and pressure moulding. The polymer, polyvinyl-chloride (PVC) was first extensively used in forming window sections in Germany during the middle of the twentieth century. The polymer in the form of unplasticised (rigid) polyvinyl-chloride (uPVC) is softened by heating, extruded through a die and pressure formed to produce hollow box sections for window frames and sashes.

High impact modified uPVC

More recently, modifiers such as acrylic have been added to the constituent materials of uPVC to improve the impact resistance of the material. The advantage of this material is that it is relatively maintenance free and will maintain its smooth textured surface for the useful life of the material with occasional washing to remove grime. As the material is formed by extrusion it is practical to form a variety of rebates and grooves to accommodate draught seals. The basic colour of the material is off-white, which is colourfast on exposure to ultra-violet light for the useful life of the material. A range of coloured plastics can be produced either with the colour integral to the whole of the material or as a surface finish. Dark colours are more susceptible to bleaching and loss of colour in ultra-violet light from the sun than light colours.

Because uPVC has less strength and rigidity than metal sections, it is formed in comparatively bulky, hollow box sections that are not well suited for use in small windows. The comparatively large coefficient of expansion and contraction of the material with the change of temperature and its poor rigidity require the use of reinforcing metal sections fitted into the hollow core of the sections to strengthen it and, to an extent, restrain expansion and contraction. The uPVC sections are screwed to the galvanised steel or aluminium reinforcement to fix the reinforcement in position, restrain deformation due to temperature movement and serve as secure fixing for hardware such as hinges, stays and bolts. Some manufacturers use reinforcement only for frame sections over 1500 mm in length and casement or sash sections over 900 mm in length. For the advantage of a secure fixing for hardware and fixing bolts it is wise to use reinforcement for all uPVC sections. uPVC windows are now extensively used for new buildings and largely as 'replacement windows' in existing buildings.
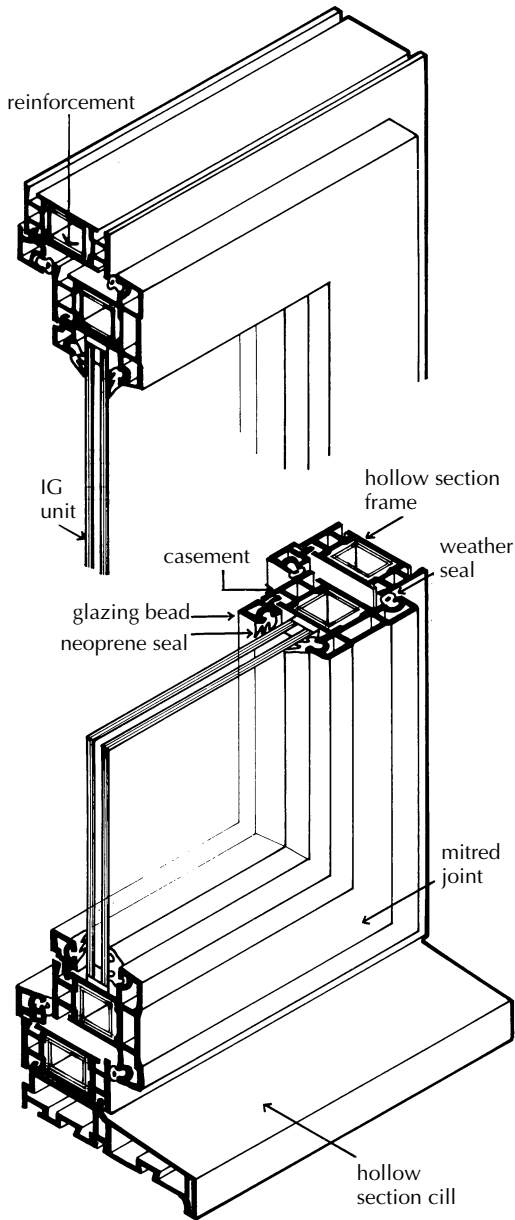
Figure 7.55   uPVC casement window.

Metal reinforcement

The extruded sections are mitre cut to length, metal reinforcement is fitted and secured inside the main central cell, and the corner joins are welded together by an electrically heated plate that melts the end material, with the ends then

brought together to fuse weld. The process of cutting and welding is fully automated, which makes it a comparatively simple operation to set the machine to make one-off sizes of windows for the replacement window market.

Mitred, welded corners

Reinforcement is fixed inside the hollows of the uPVC cells to provide rigidity to the sections that might otherwise distort due to thermal movement, handling, fixing and in use as opening lights. Reinforcement should be fitted to all frames more than 1500 mm long and all opening lights more than 900 mm long. In fire, uPVC, which does not readily ignite, will only burn when the source of heat is close to the material and will not appreciably contribute to the spread of flame. The rate of generation of smoke and fumes produced when uPVC is subject to fire is no greater than that of other combustible materials used in building.

The uPVC casement illustrated in Figure 7.55 is glazed with an IG double glazed unit set in synthetic rubber seals and fitted with weather-stripping and reinforcement of galvanised steel or aluminium sections.

Fixing uPVC frames

To avoid damage to the frames during building operations these windows are usually fixed in position after the surrounding walls have been built. Fixing is usually by driving strong screws through holes in the frame and reinforcement into surrounding walls or by means of lugs bolted to the back of frames, which are screwed to plugs in walls. Fixings are at 250 and 600 mm centres and from 150 to 250 mm from corners.

Perimeter seals to uPVC windows

The gap between the window and the surrounding wall is sealed with silicone or polyurethane sealant with backing of foamed, compressible, pre-formed strips or gunned in expanded insulation foam, adhesive foam for joints more than 6 mm wide.

Pivoted windows

Horizontally-pivoted wood window

Figure 7.56 is an illustration of a double-glazed horizontally-pivoted wood window. The frame is solid and rebated. Stop beads are fixed to the sash above and the frame below the pivots. The sash is made as separate inner and outer sashes, each of which is glazed and the sashes are normally locked together.

The purpose of forming the sash as two separate parts is so that the two parts of the sash may be opened for cleaning glass inside the space between the two parts. Reversing the sash through 180° so that the outer part of the sash may be unlocked and hinge to open into the room as illustrated in Figure 7.57 achieves this. In this position both sides of the glass in the outer part of the sash and the side of the glass of the inner part, facing the air space, may be

head of frame

rebate

post of frame

pivot

outer sash

top rail of outer sash

top rail of inner sash

planted bead

post of frame

slot for bolt

stile of inner sash

planted bead

stile of outer sash

glass

glass

glazing bead

glass

plan of jamb above pivot

planted bead

bottom rail of outer sash

bottom rail of inner sash

weathered cill

planted bead

cill of frame

planted bead   planted bead

slot for bolt

post

glass

glazing bead

plan of jamb below pivot

Figure 7.56   Horizontally-pivoted reversible window.

cleaned in safety from inside the building. The window is opened against the action of the friction pivots illustrated in Figure 7.58 and locked shut with lever operated espanolite bolts that secure the sash at four points, top and bottom, against weather-stripping.

The majority of windows fixed in recent years are glazed with IG units. The perimeter of the units is sealed around the two sheets of glass and the space between them to exclude moist air that might cause condensation on the inner faces of the two sheets of glass. Many suppliers of insulated glazing units give an assurance and guarantee that their units will maintain the perimeter seal and so prevent the entry of moisture and condensation on the inner faces of glass for up to 20 years.

Vertically pivoted steel windows

Figure 7.59 is an illustration of a steel section, hot-dip galvanised pivot window.
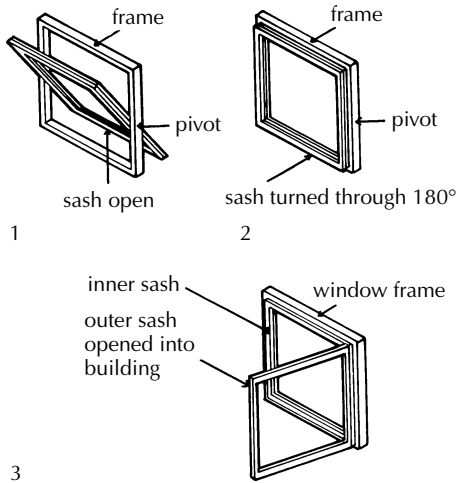
Figure 7.57   Sash reversed for cleaning glass.

Sliding windows

Vertically sliding wood sash window (double-hung sash)

This traditional window is framed from thin section timbers to form a box or cased frame inside which the counterbalance weights are suspended to support the sliding sashes, which are suspended on cords that run over pulleys fixed to the frame. The construction of the frame is shown in Figure 7.60.

Vertically sliding wood sash window with solid frame

As an alternative to the traditional system of cords, pulleys and weights to hang vertically sliding sashes, spiral sash balances have been used for the past 50 years. The spiral balance consists of a metal tube inside which a spiral spring is fixed at one end. Fixed to the other end of the spring is a metal cap through
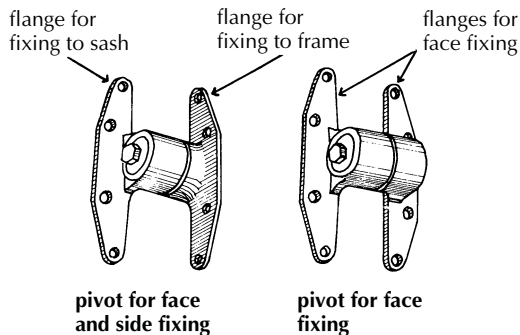
Figure 7.58   Pivots for horizontally pivoted windows.
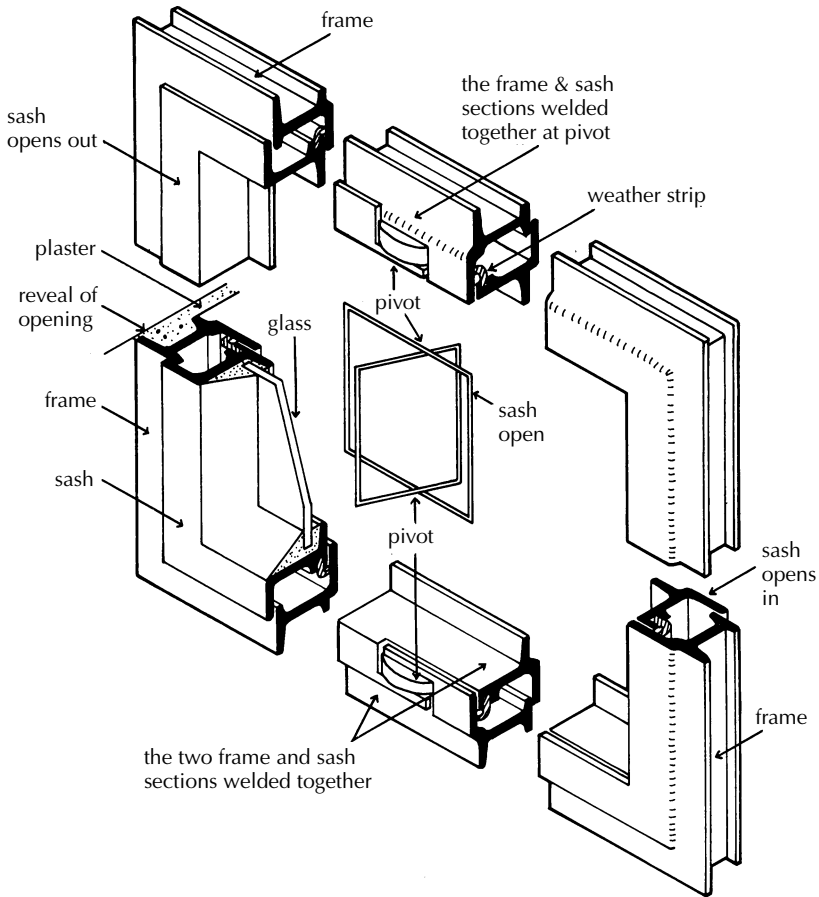
Figure 7.59   Vertically pivoted steel window.

which a twisted metal bar runs. The tube is fixed to the window frame and the twisted bar to the bottom of the sashes. As the sash is raised or lowered the twisted bar tensions the spring which supports the weight of the sashes, enabling the sashes to be raised or lowered with little effort. Figure 7.61 shows one of these sash balances.

Because of the sash balance there is no need for hollow cased frames to take counterbalances and the frame members can be made of solid sections as illustrated in Figure 7.62. The window frame is constructed from four solid rectangular sections of timber, two posts (jambs), head and cill. The posts are joined to the head and cill with combed joints glued and pinned, similar to those described for standard casements. The sashes are similar to those for windows with cased frames, the members being joined with mortice and tenon or combed joints.
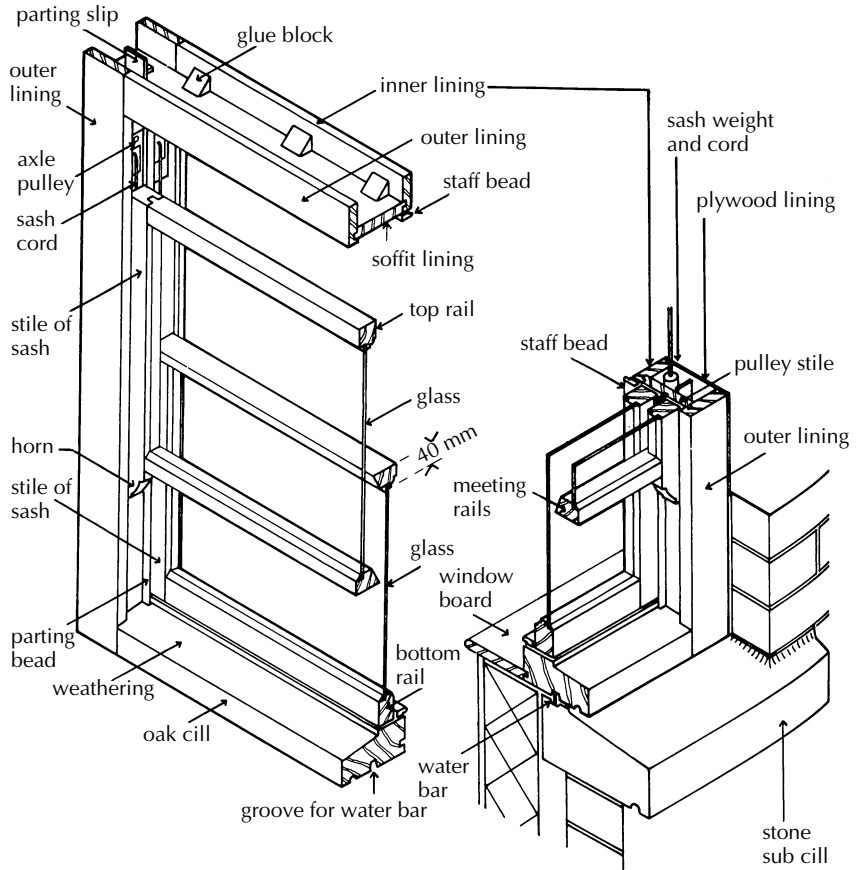
Figure 7.60   Wood vertically sliding (double-hung) sash window with cased frame.
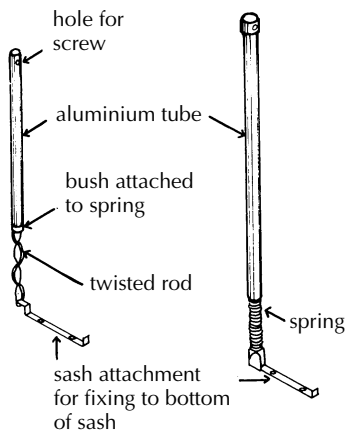
Figure 7.61   Sash balances for vertically sliding windows.
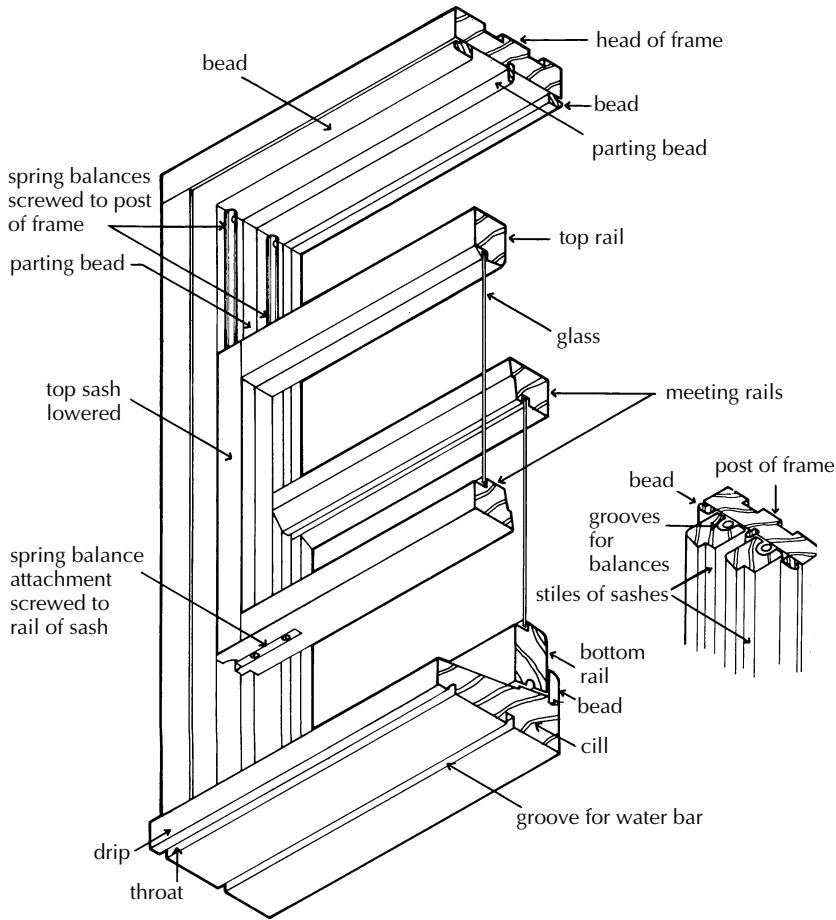
Figure 7.62   Vertically sliding sash window with solid frame and balances.

Weather-stripping

Vertically sliding sash windows are comparatively simple to weatherstrip to exclude wind and rain. Because of the vertically sliding movement of the sashes, a system of wiping, sliding seals is effective for the stiles or sides of the window, with compression seals to the head and cill of the window (Figure 7.63).

Aluminium vertically sliding sash window

With the slender sections of extruded aluminium alloy practical for use in the frame and sashes of this type of window, and because the material needs no painting at frequent intervals, aluminium vertically sliding windows have become increasingly popular. The extruded aluminium sections are joined with
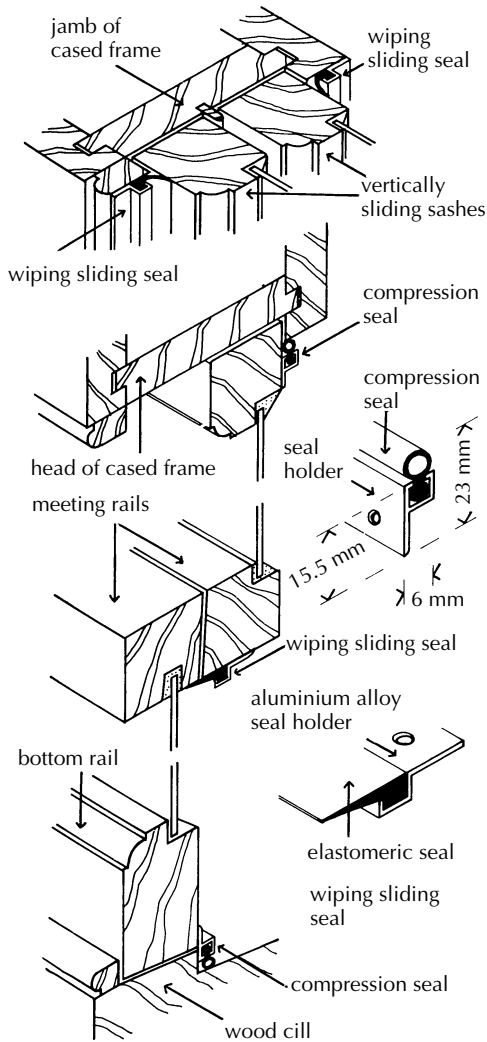
Figure 7.63   Weather seals for vertically sliding wood windows.

screw nailed butt joints, mechanical mortice and tenons or mitred and cleated joints with stainless steel screws. Figure 7.64 is an illustration of a typical vertically sliding aluminium window.

uPVC vertically sliding sash window
uPVC vertically sliding sash windows have been used as replacement windows for old wood framed windows for the advantage of freedom from maintenance in regular painting and the facility for fitting weather-stripping to grooves
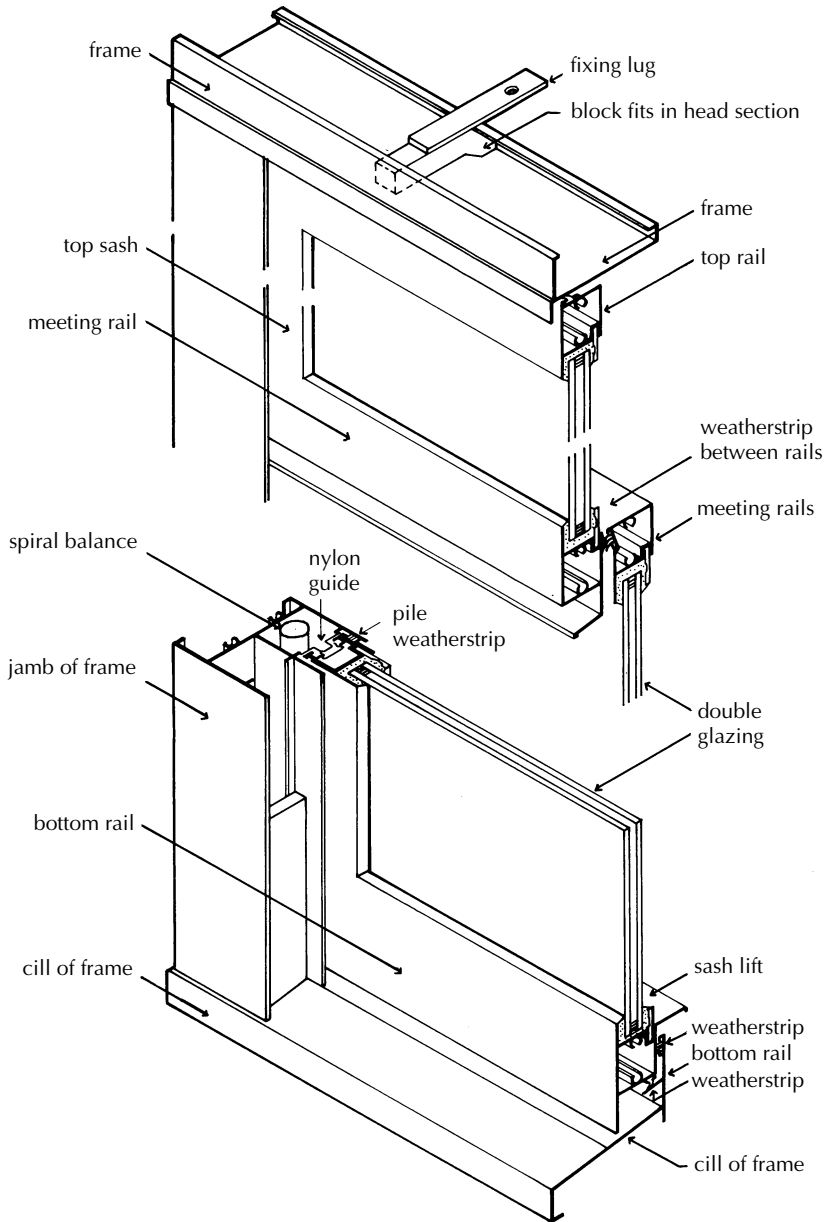
Figure 7.64   Aluminium vertically sliding sash window.

formed in the window sections. The vertically sliding, uPVC sash window illustrated in Figure 7.65 is framed with comparatively bulky hollow sections that are reinforced with metal box sections, which are designed to take double glazing units.
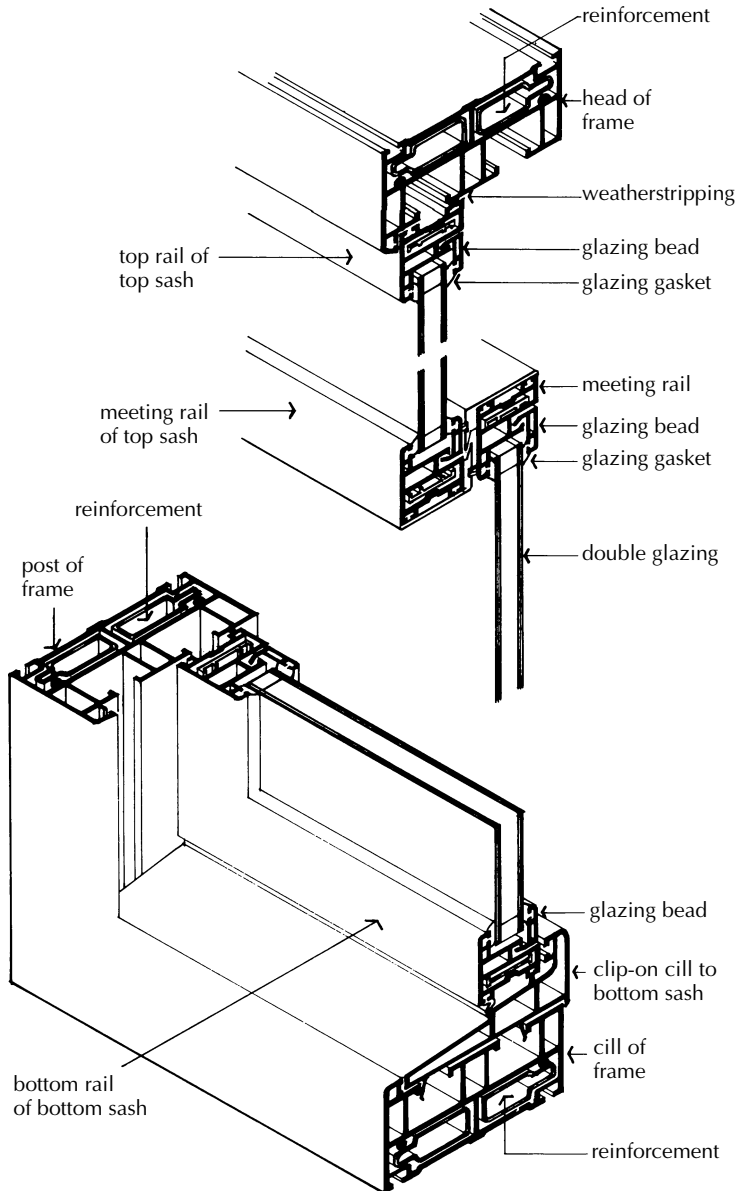
Figure 7.65   uPVC vertically sliding sash window.

Horizontal sliding windows

The aluminium section horizontally sliding sash window illustrated in Figure 7.66 slides on a bottom track with nylon filament, pile weather-stripping acting as weather seal and as guide to both top and bottom rails and with pile weather-stripping to stiles. As grit may in time collect around the track, it
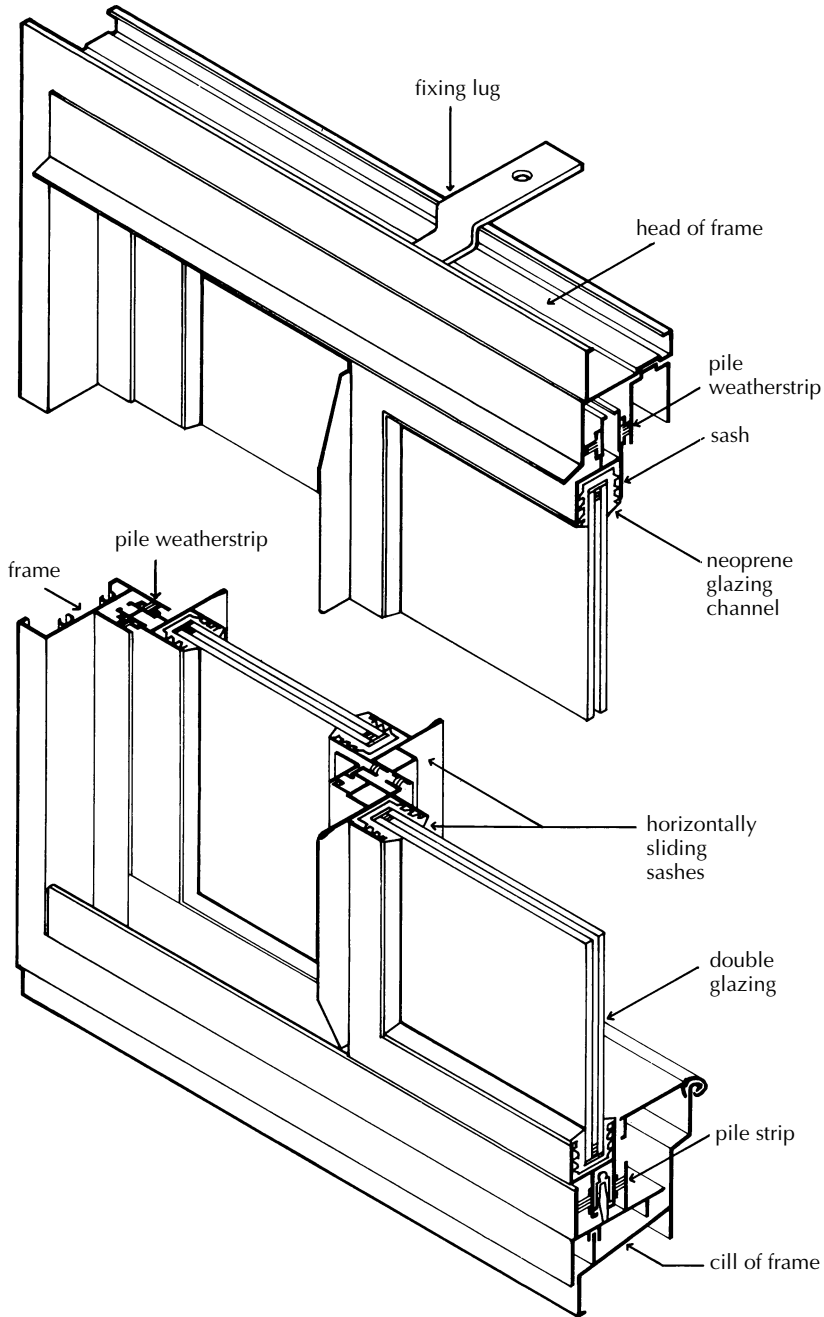
Figure 7.66   Aluminium horizontally sliding sash window.

is often somewhat difficult to open these windows, which, if forced open or closed, may tend to jam on the track and so be more difficult to open. The most common use of this type of window today is as fully glazed horizontally sliding doors, commonly called patio doors.

7.4 Glass and glazing

Glass is made by heating soda, lime and silica (sand) to a temperature at which they melt and fuse. Molten glass is drawn, cast, rolled or run on to a bed of molten tin to form flat glass. Glass may be classified into three groups:

(1) Annealed flat glasses
(2) Processed flat glasses
(3) Miscellaneous glasses

Annealed flat glasses

There are two types of annealed flat glass: float or polished plate glass and sheet glass. Clear float or polished plate glass is transparent with surfaces that are flat and parallel so that they provide clear undistorted vision and reflection. Polished plate glass is made by grinding and polishing both surfaces of rough cast glass. This type of glass has been superseded by float glass.

Float glass
Running molten glass continuously on to a bed of molten tin, on which the glass floats and flows until the surfaces are flat and parallel, makes float glass. The continuous ribbon of molten glass is then run into an annealing lehr or chamber in which the temperature is gradually reduced to avoid distortion of the glass. The glass gradually solidifies and the solid glass is cut. The natural thickness of the sheet of glass is 6.5 mm. To produce thinner glass, the molten ribbon of glass is cooled and stretched between rollers. To make thicker glass the spread of the molten ribbon is restricted to produce the required thickness. Float glass has largely replaced sheet and plate glass in this country, and is made in thicknesses of 3, 4, 5, 6, 10, 12, 15, 19 and 25 mm.

Solar control glass
Body tinted glass
Body tinted float glass or polished plate glass is transparent glass in which the whole body of the glass is tinted. This type of glass reduces solar radiation transmission by increased absorption. This material is commonly termed 'solar control glass'. Tints are usually green, grey, blue or bronze and thicknesses 4, 6, 10 and 12 mm.

Surface modified glass

Surface modified tinted float glass is transparent glass that, during manufacture, has a coloured layer of metal ions injected on to the glass. Solar control properties are provided by an increase in reflection and absorption. Thicknesses are 6, 10 and 12 mm.

Surface coated glass

Surface coated float glass (reflective float glass) is transparent glass that has a reflective surface layer applied either during or after manufacture. The reflective layer may be on a clear or a body tinted glass. Transmission of solar radiation is reduced by increase in reflection and absorption and the glass has a coloured metallic appearance. Colours are silver, blue and bronze by reflection.

Surface modified and surface coated glasses are solar control glasses that are also referred to as low-emissivity glasses. The effect of the surface coating is to reflect back into the building the long wave energy generated by heating, lighting and occupants, while permitting the transmission of short wave solar energy from outside. This type of glass is designed for use in the inner pane or sheet of glass in sealed double glazing units where the greater inside surface temperature of the glass reduces condensation and the effect of 'cold spot' discomfort.

Sheet glass
Clear sheet glass

Clear sheet (drawn sheet) glass is transparent glass manufactured by the flat drawn process in which a continuous sheet is drawn from a bath of molten glass in thicknesses of 3, 4, 5 and 6 mm. The continuous sheet is gradually cooled to minimise distortion and then cut into sheets as it solidifies. The drawn sheet is not exactly flat or uniform in thickness and will cause some distortion of vision.

Body tinted sheet glass

Body tinted sheet glass is transparent glass in which the whole body of the glass is tinted to give solar control properties. Tints are usually green, grey or bronze and thicknesses are 3, 4, 5 and 6 mm.

Cast glass (also known as patterned glass)

Clear cast glass is translucent glass made by the rolling process: the deeper the pattern the greater the obscuration and diffusion.

Body tinted glass

Body tinted glass is similar, with the whole of the glass tinted for solar control and decorative purposes.

Wired glass

Wired glass is cast or rolled with wire completely embedded in it. This type of wired glass is referred to as Georgian glass. The mesh inside the glass is 13 mm square. Cast wired glass is translucent with a cast or patterned surface. Polished wired glass is transparent, through grinding and polishing.

Processed flat glasses

Toughened glass

Toughened (tempered) glass is made by heating annealed glass and then rapidly cooling it to cause high compression in the surfaces and compensating tension in the centre of the thickness of the glass. This is a safety glazing material that is less liable to break on impact and, when broken, it fragments into comparatively harmless small pieces. Clear float, sheet, polished plate and solar control glass may be toughened.

Laminated glass

Laminated glass is made of two or more sheets (panes) of glass with an interlayer of reinforcing material between the sheets. The interlayers are permanently bonded to the enclosing sheets of glass. This glass is resistant to impact shock and when broken the reinforcing layer prevents extensive spalling of fragments. The reinforcing interlayer is usually in sheet form and made of polyvinyl butyral. This type of glass is specified as three ply, that is two sheets of glass and one of reinforcement and similarly five ply, with three sheets of glass and two of reinforcement. This type of glass is often described as safety or security glass.

Safety glass

Toughened glass and laminated glass are described as flat safety glass which, on breaking, result in a small clear opening by disintegration into small detached fragments that are neither sharp nor pointed and are unlikely to cause cutting or piercing injuries. Approved Document N to the Building Regulations defines critical locations where safety glass should be used. These critical locations are in glazed panels in internal walls and partitions between floor and 800 mm above that level and in glazed doors and door side panels, between floor and 1500 mm above that level.

Polycarbonate sheet

Flat plastic sheets made of polycarbonate are manufactured as transparent, translucent and colour tinted sheets for use as safety glazing. The sheets are 2, 3, 4, 5, 6, 8, 9.5 and 12 mm thick. The principal characteristic of this material is its high impact resistance to breakage. These sheets do not have the lustrous, fire glazed finish of glass nor are they as resistant to abrasion scratching and

defacing. A special abrasion resistant grade is produced. Polycarbonate sheet, which is about half the weight of a comparable glass sheet, has a high coefficient of thermal expansion. To allow for this, deeper rebates and greater edge clearance are recommended than for glass. To allow for the flexibility of the material and thermal expansion, one of the silicone compounds is recommended for use with solid bedding.

Miscellaneous glasses

This group of glasses includes double-glazing, roof and pavement lens lights, copper lights, leaded lights and hollow glass blocks.

Insulating glass (IG) units, double-glazing

Because of increased demand for thermal comfort in buildings, together with the requirements of the Building Regulations for energy conservation, and the continually increasing cost of fuel, it has been common for some years to fit double glazing to the majority of new and replacement windows. The term double-glazing describes the use of two sheets or panes of glass in a window or door. The type of double-glazing most commonly used today is the insulating glass unit (IG unit), which comprises two sheets or panes of glass spaced some 6, 10, 12, 16 or 20 mm apart, with a perimeter seal so that the air or gas trapped between the glass serves as thermal insulation to reduce transfer of heat through windows.

The U value (thermal transmittance) of a single sheet of 6 mm thick glass is $5.4 \, W/m^2 \, K$ and that of an IG unit with two sheets of 6 mm thick glass spaced 12 mm apart is $3.0 \, W/m^2 \, K$. The advantages of IG units are that there is some reduction of heat loss or gain as compared to single glazing and that, because of the lower U value, there is better insulation against transfer of heat. Also, a larger area of glass in windows may be used in complying with the requirements of the Building Regulations for conservation of energy. There is, in addition, some small reduction in airborne sound transmission.

Insulating glass (IG) units, sealed double glazing units

The terms double glazing, sealed double glazing and insulating glass are generally interchangeable. The term double glazing embraces all systems of double glazing whether the glazing is unsealed as in double windows or sealed as in IG units. Insulating glass units are made up from two sheets (panes or squares) of glass that are hermetically sealed to a continuous spacer around the perimeter of the unit. The usual space between the two sheets of glass is 6, 10, 12, 16 or 20 mm. Condensation will form inside the IG unit if the units are not properly sealed.

butyl-based spacer bar

aluminium spacer tube
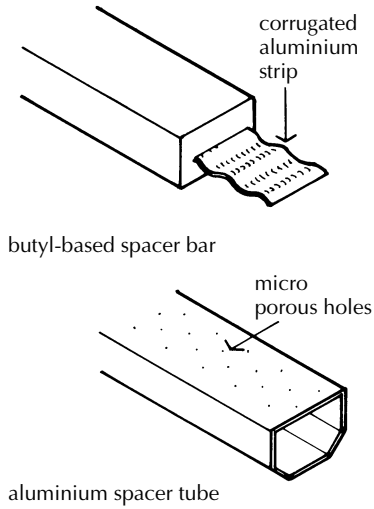
Figure 7.67   Spacer bar and tube.

Space tube or bar

The spacer which serves to seal and support the adhesive that holds the sheets of glass together is either a hollow aluminium section or a butyl-based bar with an integral aluminium strip, as illustrated in Figures 7.67 and 7.68.
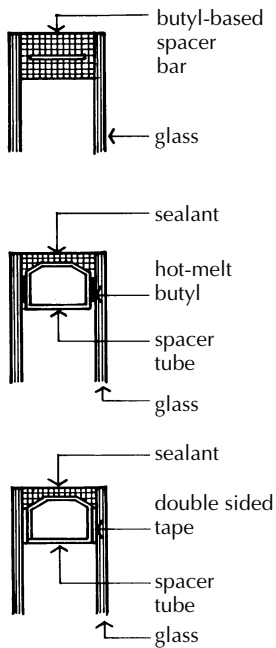
Figure 7.68   Edge seals.

The butyl-based bar, with integral aluminium strip, consists of a preformed section with a corrugated, integral aluminium strip as illustrated in Figure 7.67. The aluminium strip serves as reinforcement and in part as a barrier to moisture. A desiccant is embedded in the surface of the bar: this absorbs any moisture vapour that might otherwise condense to water on the inside faces of the glass of the unit. The advantage of the bar, commonly known as a 'Swiggle strip', is that it is continuous and being self-adhesive makes fitting more rapid than using a spacer tube and sealant.

Desiccant, dehydrated air and argon gas

The visible face of the spacer tubes is perforated with micro-porous holes to facilitate absorption of moisture vapour by the desiccant. The butyl-based spacer bar has desiccant in the face of the bar. The sealed space between the two sheets of glass is usually filled with dehydrated air. To provide somewhat better thermal insulation the space may be filled with argon gas and for better sound insulation it can be filled with SF gas.

Durability

The useful life of a double glazed unit depends mainly on the integrity of the seal as a barrier to moisture vapour penetrating the space between the sheets of glass. It is generally accepted that the useful life of sealed double glazed units is at best up to 20 years. Some assemblies give conditional guarantees of up to 15 years, conditional on workmanship in handling and fixing the units and on the glazing materials used.

Glazing

The operation of fixing glass in windows, doors and other openings is termed glazing. The purpose of glazing is to secure glass in position in window frames and sashes and to make a weathertight seal against penetration of rain around the edges of the glass. The choice of a method of glazing depends on:

❑ The anticipated structural and thermal movement of the window, and
❑ The degree of exposure of the window to wind and rain

The common method of glazing for single glazing to softwood and metal frames is putty glazing, and to hardwood, aluminium and uPVC frames is bead glazing with non-setting compounds and tapes for both single and double glazing and gasket glazing for extruded, hollow section aluminium and uPVC frames.

Single glazing – putty glazing

Putty is a material that is initially sufficiently plastic to be moulded by hand, spread in the glazing rebate as a bed for glass and finished outside as a

weathered front or face putty. The putty sets or hardens over the course of a few days to secure the glass in position and serve as an effective seal against rainwater penetration.

Glazing with putty, which dries and sets to a hard finish, is used to secure glass in wood or steel frames where there is little structural and thermal movement. Putty is not used on aluminium or plastic frames where the larger structural and thermal movement of these materials might cause the putty to crack, lose adhesion and allow rain to penetrate.

Linseed oil putty

Linseed oil putty is used for glazing to softwood and absorbent hardwood frames. It adheres to both glass and wood and hardens by absorption of some of the oil into the wood and by oxidisation. To prevent too great an absorption, softwood windows should be primed before glazing. Putty is spread by hand in the glazing rebate.

Setting and location blocks

To provide an edge clearance of 2 mm between the edges of the glass and the rebate, to allow for variations in the sash and in the glass and to facilitate setting the glass in place, setting and location blocks are used. Setting and location blocks, which are of PVC, hammered lead, hard nylon or hardwood, are 2 mm thick and up to 150 mm long. Setting blocks are pushed into the soft rebate putty in the bottom edge rebate to support the glass and the location blocks into both side rebates to centre the glass (Figure 7.69). The glass is placed on the setting blocks and pushed firmly into the putty to squeeze surplus putty between the glass and the upstand of the rebate as a back putty bed 1.5 mm thick. Glass is then secured in position, until the putty has hardened, with
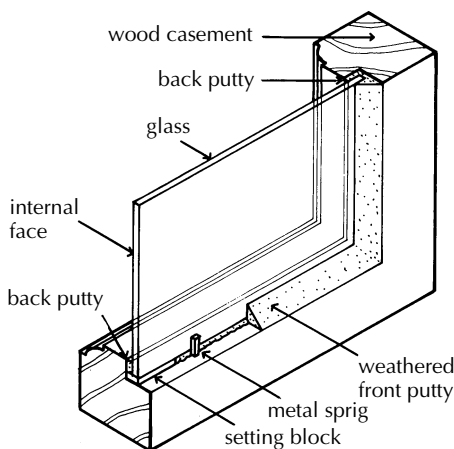
Figure 7.69   Putty glazing to wood sash.

metal sprigs (cut headless nails) that are tapped into the rebate at not more than 300 mm spacing.

Additional putty is then spread by hand in the glazing rebate around the edges of the glass and finished with a putty knife at an angle from the edge of the glazing rebate up to about 2 mm below the sight line as a seal against rain penetration. Surplus back putty is stripped and the back putty is finished at an angle up to the glass to shed any condensation water from the inside face of the glass.

The finished putty should be left to harden for at least 7 days and then painted with the usual undercoat and finish coats of paint to prevent further hardening of the putty. The painted surface should be finished on to the glass as a seal against rain penetration behind the putty.

Metal casement putty

Metal casement putty is designed specifically for use on non-porous surfaces such as galvanised steel frames, sealed timber and sealed concrete with or without glazing beads. It is made from a blend of vegetable oils selected to adhere to and set on non-porous surfaces. It is not suitable for glazing to aluminium, stainless steel, bronze or plastic finishes. When fixing glass in metal frames special metal glazing clips are required (Figure 7.70). This putty hardens and sets and will accommodate the relatively small amount of movement that occurs in steel frames due to temperature change.

Glazing with beads

As an alternative to putty glazing for single glazing, which may not always provide a neat finish, bead glazing may be used, where a bead secures the glass in place. The choice of internal or external fixing of glazing beads depends
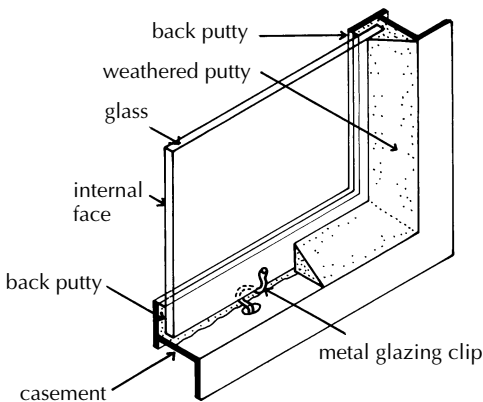
Figure 7.70   Putty glazing to metal sash.
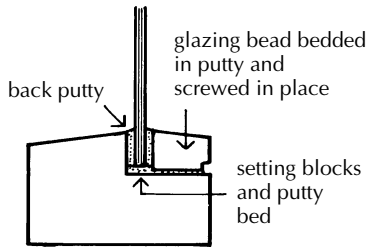
Figure 7.71   Glazing with putty and beads.

on the material of the bead, the ease of access for reglazing, appearance and security.

For durability inside glazing is preferable, particularly when softwood beads are used because the joints between the bead, the glass and the frame are vulnerable to the penetration of rain. For access for reglazing and security reasons inside beads are best for ground floor windows.

Glazing with putty and beads

Glazing with putty and beads may be used for softwood, absorbent hardwood and galvanised steel frames. In sheltered positions the beads may be external, for other exposures they should be internal.

Sufficient putty is spread all round the rebate to provide adequate back putty. Setting blocks are pressed into the putty in the platform rebate and location blocks as necessary. The glass is placed on the setting blocks and pressed firmly into the rebate so that putty 1.5 mm thick is squeezed between the glass and the back of the rebate as back putty bedding as illustrated in Figure 7.71.

For fixing externally, beads should be bedded with putty against the glass and to the bed of the rebate. The beads are pressed firmly against the glass and then secured with pins or screws. Where beads are fixed internally it is not usual to bed them in putty. Back and front putty beds are trimmed and finished with a slope up to the glass. The exposed putty should be painted some 7 to 14 days after glazing. For putty glazing to non-absorbent hardwood and galvanised steel frames metal glazing putty is used.

Glazing with tape and beads

As an alternative to putty glazing for large squares of glass for both wood and galvanised steel frames, load-bearing mastic tape and a sealant may be used.

Load bearing mastic tape is made from compressed fabric and butyl in various widths and thicknesses. The tape used as bedding for glass will also serve as a sealant to exclude rain when it is adequately compressed. It is comparatively easy to use and often preferred to putty. A strip of the mastic tape is pressed into position all round the rebate upstand so that it finishes some 3 to 6 mm below the sight line and setting blocks are placed in the rebate base.
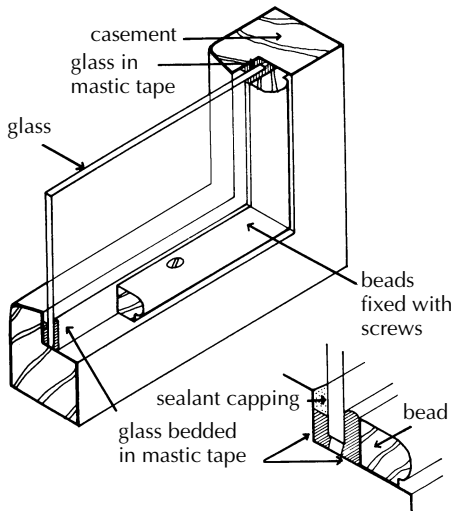
Figure 7.72   Glazing to wood with beads.

Glass is placed on the setting blocks and firmly pressed into the rebate to compress the tape to the rebate upstand. Location blocks are fixed in the side edge clearances to centre the glass.

A second strip of mastic tape is fixed around the outside edges of the glass and the internal glazing beads are fitted in place, pressed firmly against the mastic tape and screwed into position. A sealant is run, by gun, into the edges of the outside of the glass and finished with a smooth chamfer or slope to shed water as illustrated in Figure 7.72.

Glazing IG units
Insulating glass units are hermetically sealed and subject, therefore, to continuous flexing due to changes in atmosphere and temperature. The glazing materials that are used must allow for thermal and structural movement of both the IG unit and the window framing. The glazing method used should allow for movement and prevent water penetrating to the edges of the IG unit.

Setting, location blocks and distance pieces
To accommodate movement between glass and window frames, casements or sashes, due to different thermal and mechanical movements, a minimum clearance must be allowed all round IG units of from 3 mm for glass up to 2 m wide to 5 mm for glass over 2 m wide at sides and top of unit, and 6 mm at cill level.

Setting blocks and location blocks should be of some resilient, non-absorbent material such as sealed teak or mahogany, hammered lead, extruded uPVC, plasticised PVC or neoprene. The width of setting blocks should be equal to
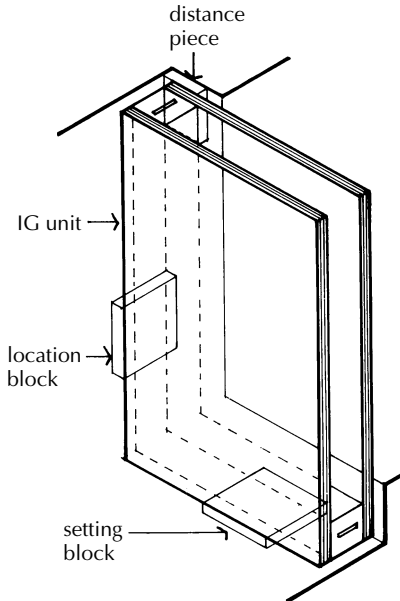
Figure 7.73   Blocks for IG units.

the thickness of the IG unit plus the backface clearance and at least 25 mm long. Location blocks should be 3 mm wider than the IG unit and at least 25 mm long.

Distance pieces are used to prevent displacement of glazing compounds or sealants by wind pressure on the glass, by retaining the IG unit firmly in the window. Distance pieces should be used except where load bearing tapes or putty are used for stepped units. Distance pieces should be the same thickness as face clearance and made of a resilient, non-absorbent material similar to that for setting blocks (Figure 7.73).

Factory glazing, site glazing

Insulating glass units may be delivered to site factory glazed to windows. The advantage of factory glazing is that the operation of glazing can be carried out under cover in conditions most suited to making a good job. The disadvantage of factory glazing is the possibility of damage to the glazed window in transit and through handling on site. The best conditions for glazing are clean, dry surfaces to which bedding and sealant materials can adhere. Because such conditions are rare on most building sites, factory glazing should have advantage over the other option, site glazing.

Glazing methods

The two systems of glazing used for insulating glass (IG) units are solid bedding and drained methods.

(1) *Solid bedding*. The solid bedding method depends on the use of mastic bedding materials around the edges of the IG unit, inside the glazing rebate, with sealants to prevent the penetration of water to the edges of the unit. This method of bedding is most suited to window frames with plain, square sections and rebates such as wood or steel windows into which the unit may be bedded and secured with beads.

(2) *Drained glazing*. The drained method of glazing is designed to encourage water, which may have penetrated the glazing rebate around the edge of the IG unit, to drain to the outside. This method of glazing, which is particularly suited for use with the systems of gasket glazing commonly used with extruded, hollow sections of uPVC and aluminium windows, may be employed with plain section wood, steel, aluminium and uPVC windows.

Whichever method is used, the first defence against penetration of water to the edge seal of the IG units is the mastic or rubberised edge seals to glass, which should at once accommodate movement and act as a seal against water. Drainage is a back up to drain any water that has penetrated. To be effective, the drainage system should at once be adequate to drain water, be protected against wind-blown rain and remain clear of obstruction during the useful life of the window.

Beads with non-setting compound

This is the most straightforward method of bedding IG units in window frames of wood or metal, where one material is used both as bedding and sealant.

The bedding-sealant materials that may be used are non-setting compounds of synthetic rubber, oils and filters or low permeability one- or two-part curing sealants such as polysulphide, silicone or urethane base.

The clean rebates and wood beads are first primed or sealed. A generous fillet of bedding material is spread in the rebate into which setting blocks and distance pieces are pressed. The distance pieces are necessary to maintain the correct thickness of bedding, behind the glass, against wind pressure on the glass. The glass is then placed on the setting blocks and pressed firmly into the rebate against the distance pieces to provide a 3 mm thick back bedding. Location blocks are fixed in the side edge clearance. Bedding material is spread around the edges of the glass to fill the edge clearance gaps around the IG unit. A substantial fillet of bedding material is spread in the glazing rebate. The wood beads are bedded in position and pressed firmly into the bedding material so that there is 3 mm of bedding between the glass and the bead and a thin bedding below the bead. The wood beads are secured in place with screws at maximum 200 mm centres and no more than 75 mm from corners. The bedding inside and
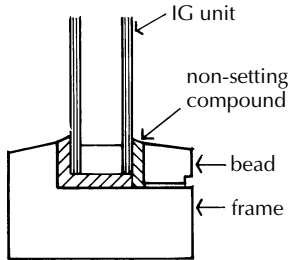
Figure 7.74   Solid bedding glazing.

out is trimmed and finished with a smooth chamfer or slope to shed water as illustrated in Figure 7.74.

Beads with load-bearing tape and sealant

An alternative method of solid bedding for IG units glazed to wood and metal frames uses load-bearing mastic tape or cellular, adhesive sections as face bedding and non-setting sealant as capping and bed for units.

Pre-formed load-bearing mastic tape is made from a fabric base, saturated in butyl (synthetic rubber) or polyisobutylene polymers in various widths and thicknesses. The tape is compressed during manufacture so that it has adequate loadbearing capacity as bedding for glass, to resist wind pressure on the unit. A strip of mastic tape is fixed to the rebate upstand with its top edge about 6 mm below the sight line and setting blocks are placed in the rebate platform to support the IG unit. The IG unit is placed on the setting blocks and pressed firmly into the rebate up to the mastic tape in the upstand of the rebate.

One-part or two-part sealant of polysulphide, silicone or urethane is run into the clearance gap between the lower edge of the IG unit and the rebate as bedding and as a thin bed for the glazing bead. A strip of loadbearing tape is run around the outside edge of the unit or the back face of the bead so that its top edge finishes some 6 mm below the sight line. The beads are fixed in place and pressed in firmly to compress the tape and bed the wood beads, which are screwed in place at a maximum of 200 mm and no more than 75 mm from corners.

Sealant capping is run around both sides of the glass and finished with a slope or chamfer as illustrated in Figure 7.75. Various combinations of load-bearing tapes and sealants, non-setting compounds and sealants and sealants by themselves may be used as bedding and sealants for solid bedding glazing of IG units, depending on the nature of the materials of the window framing and convenience in the operation of glazing.
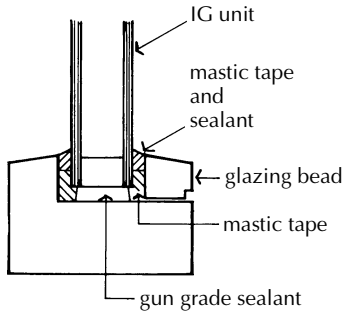
Figure 7.75   Solid bedding glazing.

Drained glazing

The drained method of glazing for IG units is designed to remove any water that has penetrated to the bottom rebate by drainage and to some extent by ventilation. Any water that lies for some time in the bottom rebate will adversely affect the adhesive edge seal to IG units.

Insert gasket glazing

The majority of extruded, hollow section uPVC and aluminium window frames employ gasket glazing systems. Gaskets are preformed sections of synthetic rubber that are shaped for insertion between the nibs around a groove in the glazing bead or the frame of the window and so positioned that the blades or bearing edges of the gasket make firm contact with glass faces as illustrated in Figure 7.76, to exclude rain and allow for some structural and thermal movement between frame and IG unit.

Drainage to square section frames

As an alternative to solid bedding for square section wood and metal frames, systems of face bedding or gasket glazing with drainage to the bottom rebate may be used. For drainage the bottom rebate platform should be cut to slope out at an angle 10° to the horizontal. Drainage of water is through holes in the underside of the oversize bottom bead (Figure 7.77).

Double and triple glazing for sound insulation

A major part of the penetration of sound through windows is transmitted as airborne sound through gaps between opening sashes and frames of windows. Appreciable reduction of sound transmission through windows can be achieved by fitting weather seals around all opening parts. When indoor quiet is at a premium and windows are necessary for daylight, double-glazing with a comparatively wide air space between sheets of glass may be used for additional reduction of sound transmission. In effect two windows are built into
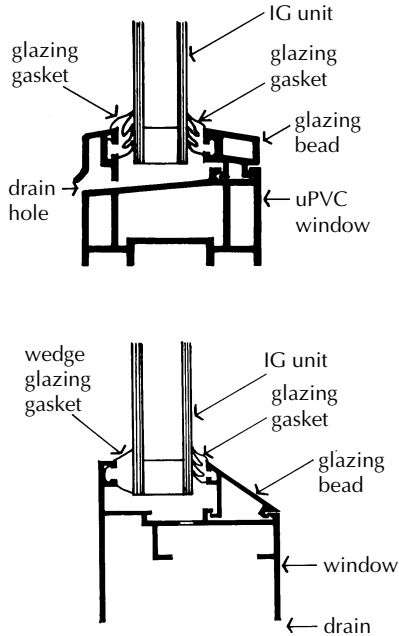
Figure 7.76   Drained glazing.

the opening, separated and not connected, by some 150 mm between the two sheets of glass as illustrated in Figure 7.78.

The outer window consists of a fixed light and the inner window is hinged to open inwards for the purpose of cleaning glass facing the cavity. This opening light is fitted with weather-stripping. The inside of the cavity is lined with an acoustic lining made of a material that will absorb some of the energy causing the air movement that causes sound. By fixing the two windows separately, vibrations of the outer sheet of glass, caused by airborne sound, will be reduced
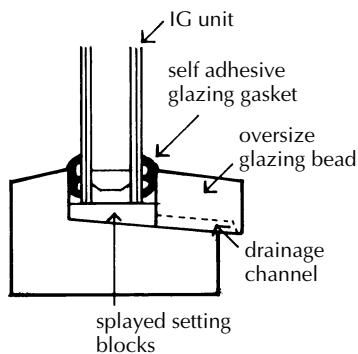
Figure 7.77   Drained glazing.
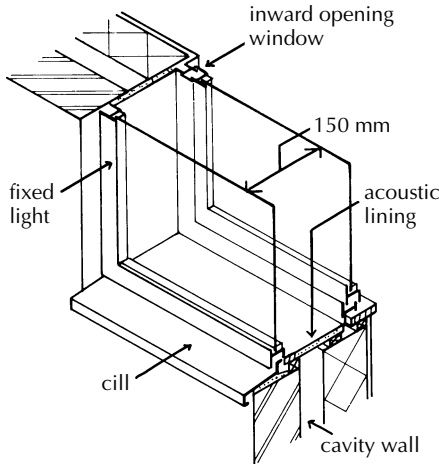
Figure 7.78   Double window for sound insulation.

by the still air in the wide cavity and so have less effect on the inner sheet of glass. Triple glazing with large cavities will provide considerable sound insulation.

7.5 Hardware

Hardware is the general term used to describe the window furniture, such as hinges, locks and stays. Ironmongery and window furniture are also terms in common usage.

Hardware for timber windows
Wood casements, ventlights and sashes are hung on a pair of pressed steel butt hinges similar to those used for doors. To inhibit rusting the hinges are galvanised and finished with a lacquer coating. As an alternative, metal off-set hinges may be used for casements, in which the pin is offset outside the casement so that when the casement is open there is a gap between the hinged edge of the casement and the frame sufficient to allow for cleaning the outside of the glass from inside the building.

To secure casements, sashes and ventlights in the closed position a casement or window fastener or latch is fitted halfway up the height of casements and in the centre of ventlights. These fasteners operate through a latch, which is fixed to the opening casement, and engages a keep fixed to the frame as illustrated in Figure 7.79. The handle of the latch is raised to release the latch to open the window. For security the majority of window latches are lockable by a loose key that operates a lock in the latch.

Some care should be taken in fitting casement fasteners and keeps so that when the fastener is closed it firmly closes the casement on to flexible weather-stripping fixed in the rebate of the window frame around the opening
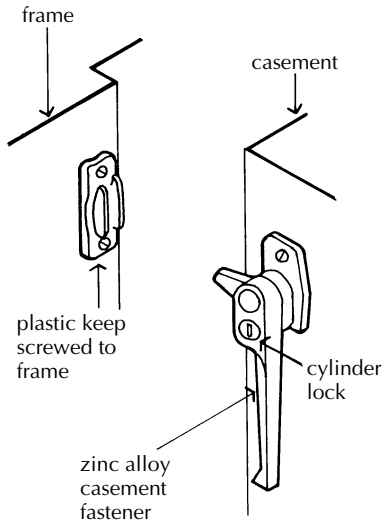
Figure 7.79   Lockable casement fastener.

light. Casement fasteners are made of cast zinc, aluminium or steel, usually finished with a protective coating of anodising powder or liquid organic coating or plastic.

To maintain opening lights in a window in a chosen open position, casement stays are fitted to the bottom rail of opening lights, as illustrated in Figure 7.80. The conventional form of these stays is a casement stay fixed to the bottom
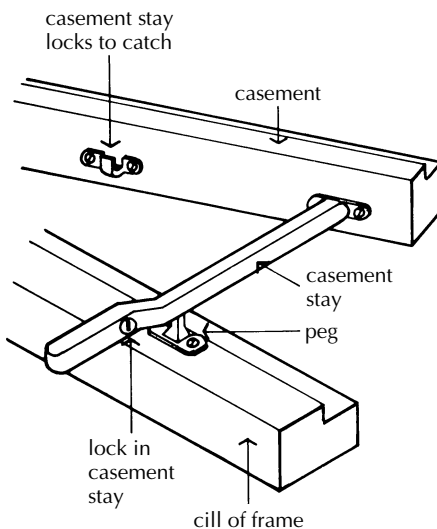
Figure 7.80   Lockable casement peg stay.

rail of the sash, which engages a casement peg fixed to the cill of the window frame. Holes in the stay provide a selection of possible openings. The stay, which pivots in its fixing, can be secured in a catch, fixed to the bottom rail of the sash when the window is in the closed position. Stays are made of cast zinc, aluminium or steel which is usually finished to match the protective coating of fasteners.

Hardware for aluminium frames

The hardware of hinges, lockable casement fasteners and stays are made of anodised finish, cast aluminium or die-cast zinc alloy, chromium plated.

Hardware for uPVC frames

Hardware is made from cast aluminium alloy and die-cast zinc alloy with anodised, powder or organic liquid coatings for lockable fasteners and stays that are screwed through the outer wall of the uPVC sections into the reinforcement.

7.6 Window cills

It is good practice to set the outside face of windows back from the outside face of the wall in which they are set, so that the reveals of the opening give some protection against driving rain. The function of an external window cill is to conduct the water that runs down from the windows away from the window, and to cover the wall below the window and hence exclude rain from the wall immediately below the window. The material from which the cill is made should be sufficiently impermeable and durable to perform this function during the life of the building. The internal cill of a window serves the purpose of a finish to cover the wall below the window inside the building, and as a stop for wall plaster. The material used for internal cills should be easy to clean and materials commonly used are painted softwood (or mdf), plastic or ceramic tiles.

External cills

External window cills are formed either as an integral part of the window frame, as an attachment to the underside of the window, or as a sub-cill, which is in effect a part of the wall designed to serve as a cill. Most materials used for external cills are pre-formed so that the dimensions of the cill determine the position of the window in relation to the face of the wall. As a component part of a wall, external cills should serve to exclude wind and rain and provide adequate thermal insulation to the extent that the cill does not act as a thermal bridge. The materials used are natural stone, cast stone, concrete, tile and brick. Natural sedimentary igneous and metamorphic stone cills are less used than cast stone, concrete, tile and brick cills due to the cost of the material. Slate
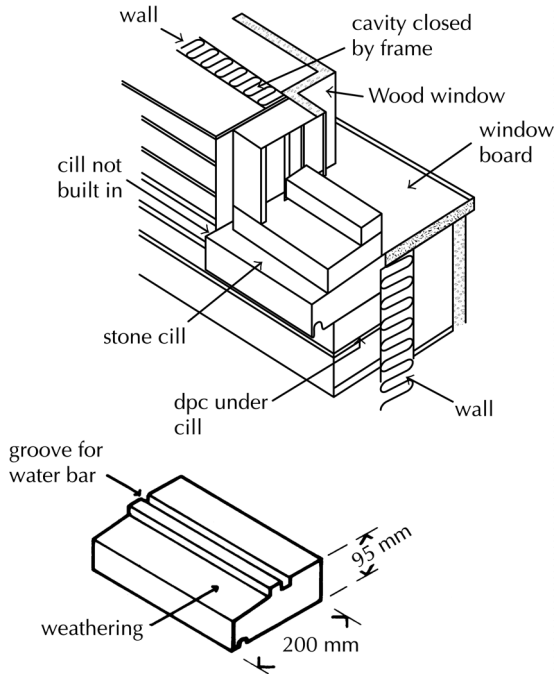
Figure 7.81 Natural stone or cast stone cill for wood window.

cills, which are readily available, but comparatively expensive, are used to some extent.

Natural stone cills

Natural stone cills are specially cut to section to provide a weathered surface, a groove for a water bar and an overhanging drip edge as illustrated in Figure 7.81. The top surface of the cill is finished flat, as a bed for the window cill. A groove is cut in the top of the cill to take a metal water bar that is set in mastic in the stone cill and the underside of the wood window cill. The water bar acts as a check against wind-driven rainwater that might otherwise penetrate between the stone sub-cill and the timber window cill. A shallow sinking is cut in the top of the cill down to a weathered face that slopes out to shed water. The shallow sinking acts as a check against wind-driven rain being blown up the weathered cill face. A shallow groove is cut near the outside edge of the underside of the cill to form a drip edge to encourage rainwater to run off.

Stooled ends to stone cills provide a solid bearing to walling at jambs and a weather seal against water penetrating between cill and jamb. Cills with stooled ends are commonly used with stone walling so that the cill may bond
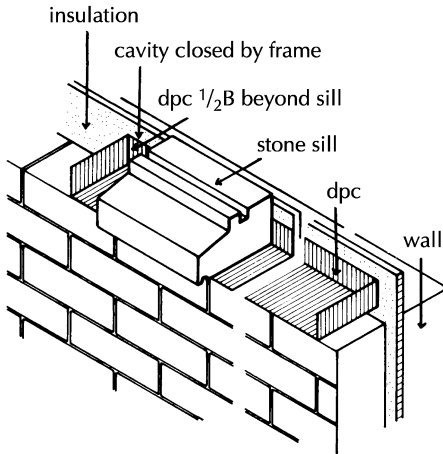
Figure 7.82   Under-cill dpc.

in with stonework. Stone sub-cills are bedded in mortar on the under-cill dpc, bearing on the outer brick leaf of the cavity wall. As the cill does not extend across the total width of the cavity wall it should not act as a thermal bridge. Reconstituted and precast concrete cills represent a cheaper alternative to natural stone cills. Cills of stone, reconstructed stone and precast concrete with square ends and cills of small units such as brick and tile may not be entirely effective in excluding rain that may penetrate joints in and at the ends of cills to the wall below, particularly in exposed positions. It is practice, therefore, to build in a sub-cill dpc as illustrated in Figure 7.82.

Slate cills
Slate cills are available in a range of standard and purpose-made sections to suit either timber or metal windows. This dense, durable material is impermeable to water, requires no maintenance, is a poor thermal insulator and, being brittle, may crack due to movement of the building fabric. These cills should be cut and finished in one length to avoid the difficulty of making a weathertight joint in the material, a limitation that restricts their use to comparatively narrow windows unless a generous thickness of slate is used. The two standard sections illustrated in Figure 7.83 are for use with standard steel windows, which are screwed to the fillet fixed to the cill. Cills for use with wood windows are finished with a groove for a water bar. These cills are bedded in mortar on the wall below the window with the drip edge projected some 38 mm beyond the face of the wall.

Brick cills
A method of forming sub-cills to window openings in walls of fairface brickwork is with a course of bricks laid on edge or a course of brick specials.
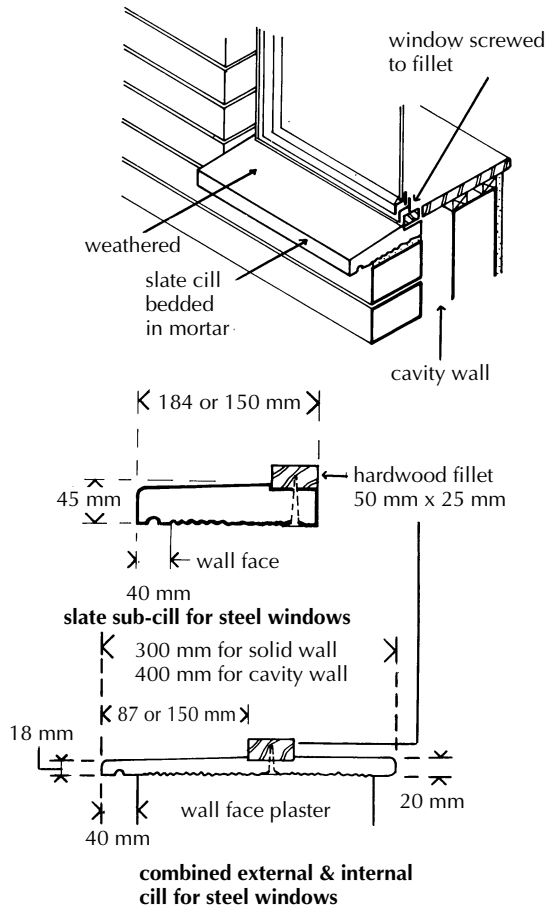
Figure 7.83 Slate cills for steel windows.

Whichever method is used the bricks should be sufficiently dense and weather resistant to stand the appreciable volume of rainwater that will run off the impermeable surface of the glass above. Standard size bricks are laid on edge as cills with one stretcher face and one header face exposed. The stretcher face top surface of the cill may be laid to a slight fall to shed water. The bricks are laid and pointed in cement mortar with the back edge of the bricks at least 30 mm behind the window cill edge and finished either flush with or projecting from the wall face as a drip edge. The special plinth bricks, illustrated in Figure 7.84, are made from dense clay and formed with a sloping weather face to shed rainwater. The bricks are laid on bed in cement mortar with the back face of the bricks set well back under the window cill so that there is a generous overhang of the drip edge of the wood cill above. A dpc is bedded below the
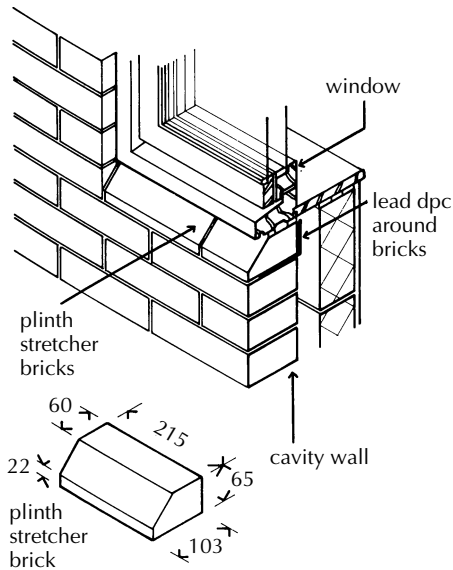
Figure 7.84   Brick cill.

cill bricks, turned up behind them and continued $\frac{1}{2}$B beyond the jambs of the window opening.

Tile cills

As a comparatively cheap form of cill, two courses of clay or concrete plain tiles are laid, breaking joint, in cement mortar. Machine pressed or concrete plain tiles, which may resist the likelihood of frost damage at a slope of 30° are used. The tiles may be laid with their long axis parallel to the wall face to avoid cutting tiles or with their long axis at right angles to the wall and cut as necessary to suit the position of the window. The tiles may be finished square to the jambs of the window opening or notched around the angle of the jambs for appearance sake, as illustrated in Figure 7.85. The tiles should be laid with their back edge well back under the window cill, so that there is a generous overhang of the window cill, and project out beyond the wall face about 38 mm as a drip edge. A dpc should be bedded below the tile cill and bedding.

Metal cills

Most metal window manufacturers provide standard section metal cills for fixing to the frame of their windows to give cover and protection to the wall below the window. The projection of the cill beyond the face of the wall is determined by the 25 mm width of the welded-on stop ends, which in turn determines the position of the window in the thickness of the wall. The joint between the ends of the cill and the jambs should be pointed with mastic. The
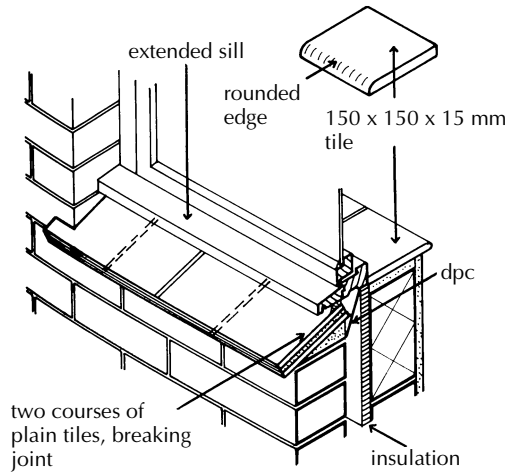
Figure 7.85   Plain tile cill.

steel cill itself will exclude rainwater but the end joints may be vulnerable to water, particularly in positions of severe exposure. A dpc in the course below the cill, extending each side of the opening, might be a wise precaution in conditions of severe exposure. Similarly, extruded aluminium section cills are made to suit aluminium windows as an integral part of the window.

Plastic cills

Most plastic windows have an integral cill as part of the window, which fits over some form of sub-cill. Some manufacturers provide a separate hollow section plastic cill, which is weathered to slope out and is designed to cover and protect the wall below the window. These separate cill sections are clipped or screwed to the frame, as illustrated in Figure 7.55.
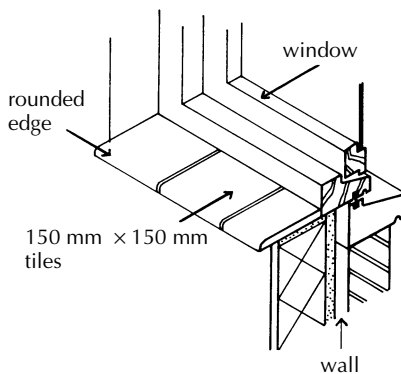
Figure 7.86   Tile internal cill.
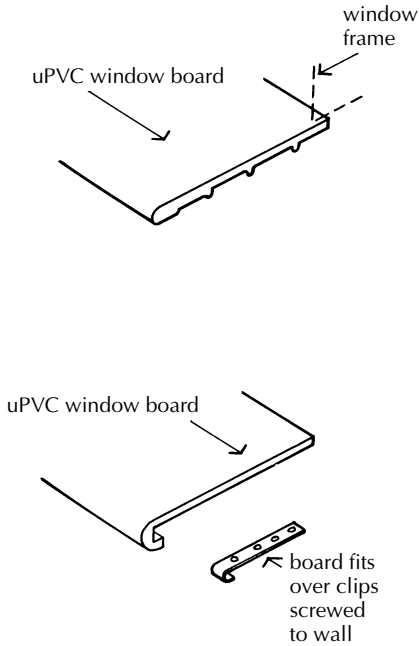
Figure 7.87   Plastic windowboards.

Timber cills

Most standard section timber windows can be supplied with a timber cill section that is tongued to a groove in the cill of the frame so that it projects beyond the window either to cover and protect the wall below or to overlap a sub-cill.

A Centre pivot and turn	B Top hung	C Bottom hung and centre pivot	D Vertical tilt with top
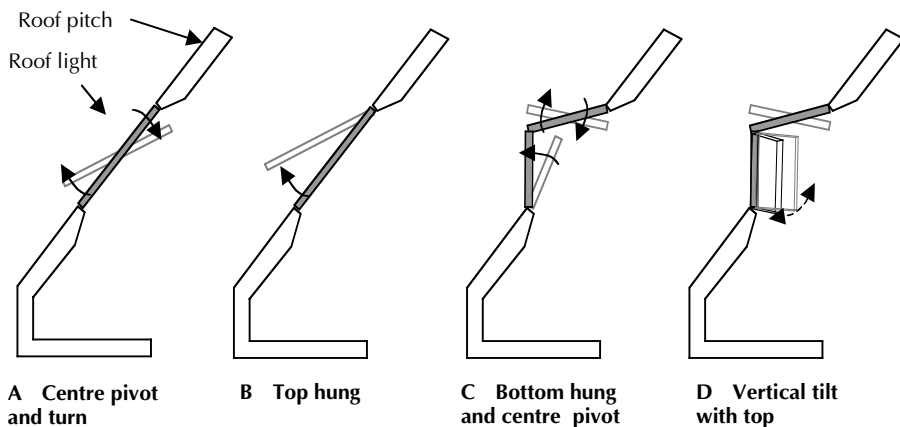
Figure 7.88   Types of roof windows – roof lights (Velux).

Interlocking tiles

Tile battens

Flashing

Tilting roof light

Support bracket

Flashing
Lead apron

Trimmer joists between
rafters

Breathable vapour barrier

Counter battens

Window frame

Rebate to accommodate wall
finish

Window lining – part of window
frame seen once wall finish is
applied

Control bar – operates window
and ventilation

Venilation flap

Centre pivot windows rotate
through 160°

Triple glazed unit

Casement

Window frame

Figure 7.89   Roof light (Velux).

The cill is designed to project some 25 to 38 mm from the face of the wall as a drip edge and should be protected with paint or stain and regularly maintained. It is sensible to use hardwood cills in positions of moderate and severe exposure. The cill fits between the jambs of the opening, and the end butt joints should be bedded in mortar and pointed with mastic.

Internal cills

The surface of the internal cill should be such that it can easily be kept clean. A common form of internal cill is a softwood board, termed a window board, cut from 19 or 25 mm boards and wrought smooth on one face and square or rounded on one edge. The board may be tongued to fit to a groove in wood window frames. The board is nailed to plugs or bearers nailed to the wall so that it projects some 25 mm or more from the finished face of plaster, as illustrated in Figure 7.81.

Clay or concrete tiles may be used as an internal cill. The tiles are bedded in mortar on the wall and pointed in cement, as illustrated in Figure 7.86. Rounded edge tiles are used and laid to project beyond the plaster face.

Various sections of plastic windowboard are made for use with uPVC and other windows and as replacement windowboards. The thin sections are of co-extruded uPVC with a closed cell, cellular core and an integral, impact modified uPVC skin. The thicker sections are of chipboard to which a uPVC finish is applied on exposed faces. The advantage of these windowboards is that they do not require painting and are easily cleaned. The disadvantage is that sharp objects fairly readily deface them and the damage cannot be made good. Plastic windowboards are cut to length and width with woodworking tools and fixed with concealed fixing clips, mortar bedding or silicone sealant adhesive, or are nailed or screwed to prepared timber grounds with the nail or screw heads covered with plastic caps (Figure 7.87).

7.7 Roof lights

Windows that are housed within the roof rafters and follow the line of the roof are termed roof lights. Where the roof space is large enough to accommodate an extra room, roof lights offer a cost effective method of incorporating a window within the attic space. The most common form of roof light is the centre-pivot window, which can be rotated through 160°, allowing cleaning from the inside. A wide range of roof windows such as fixed, top-hung, tilt and turn, and bottom-hung windows are now available (Figure 7.88). Modern roof lights are supplied as prefabricated units with flashings to suit. Figure 7.89 shows a typical roof light.

8 Doors

A door is a solid barrier that is fixed in an opening in a wall to hinge, pivot or slide open (or to close). The door opening, doorway, allows access and egress from buildings and between rooms, compartments and corridors. As a component part of a wall the door and its frame are integral to the overall performance of the wall.

8.1 Functional requirements

The functional requirements of doors are specified, relating to both the component parts and the whole of the door sets or assemblies. The primary function of a door when open is to allow:

❑ Safe means of access and egress

The functional requirements of a door, when closed, are:

❑ Security, prevention of unauthorised entry
❑ Privacy
❑ Strength and stability
❑ Resistance to weather
❑ Durability and freedom from maintenance
❑ Fire safety
❑ Resistance to the passage of heat
❑ Resistance to the passage of sound
❑ Airtightness
❑ Aesthetics

Safe means of access and egress
The Approval Document to Part M of The Building Regulations suggests means of approach and minimum door sizes for doors for access to buildings. Approved Document M requires there to be reasonable provision for disabled people to gain access and use the building and its facilities in all new dwellings, as well as other types of new buildings. While Document M deals with disabled access its provision now extends to use of buildings by the general public.

A door opening should be sufficiently wide and high for reasonably comfortable access of people, regardless of their ease of mobility. The standard width

Table 8.1   Effective clear widths of door openings.

Minimum effective width of doors Approved Document M		
Direction and approach width	New buildings (mm)	Existing buildings (mm)
When approaching head on, without a turn	800	750
At right angles to an access route at least 1500 mm wide	800	750
At right angles to an access route at least 1200 mm wide	825	775
External doors to buildings used by general public	1000	775

and height of 762 and 1981 mm (the metric equivalent of the former imperial sizes of $2'6'' \times 6'6''$) for single leaf doors will be found in the majority of existing houses. To allow comfortable access for people with disabilities the minimum clear opening for a single door should be 800 mm. Clear opening widths can be achieved by selecting a 1000 mm single leaf door set (850 mm clear opening width of leaf) or a 1.8 m double leaf door set (810 mm clear opening width of each).

Doors and design considerations (Approved Document M)
Approved Document M requires that the external entrance door to dwellings has a minimum clear opening width of 775 mm. Table 8.1, also from Approved Document M, gives minimum effective clear widths of entrance doors used by the general public as 1000 mm in new dwellings and 775 mm in existing buildings.

For door widths of 800 mm or less, Approved Document M gives guidance on the widths of corridors. Table 8.2 shows the minimum requirements for access routes within buildings for disabled use in relation to a range of door widths. Before selecting a door size, consideration should be given to the width of the corridor in which the door is to be positioned.

Double leaf doors are commonly used for access to large spaces or rooms and for convenience in busy corridors. Where the door is an entrance door

Table 8.2   Minimum widths of passageways for a range of door sizes.

Minimum width of passageways in relation to door openings Approved Document M	
Doorway – clear opening width (mm)	Passageway width (mm)
750 or wider	900 (when approaching head on)
750	1200 (when approaching at an angle)
775	1050 (when approaching at an angle)
800	900 (when approaching at an angle)

Minimum clear
opening 800 mm

300 mm

Glazed doors

1500 mm

minimum
visibility

900 mm

A   Clear opening (single door) – plan

B   Glazed panels in entrance doorways – elevation
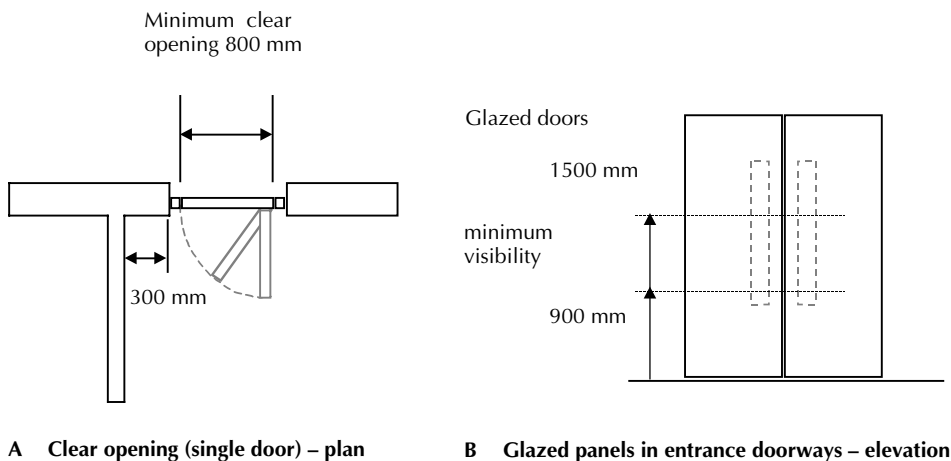
Figure 8.1   Doors: Disabled access.

allowing disabled access, glazed panels as shown in Figure 8.1 should be used.

The side on which the door is hung by hinges or pivots, its hand or handing, and whether it opens into or out of a space or room, are a matter of convenience in use. By convention, doors usually open into the room of which they are part of the enclosure. There have been systems of describing the hand of doors by reference to opening in or out and as either left-hand or right-hand, clockwise or anti-clockwise. These are of very little use because of the difficulty of clearly defining what is outside and what is inside. If a doorway is used as part of an escape route, the door should be hung so that it opens in the direction that people will egress the building.

Doors can be hazardous and consideration should be given to the ability of people to distinguish a door from a clear opening (which may be a problem with glass doors). The presence of a door should be apparent when it is both open and closed; measures should be taken to avoid people walking into doors which are retained in the open position. Consideration should be given to those who are visually impaired who will use the doors. Further considerations are required under Approved Document M when glass doors are used; this is discussed later.

Door closers in public buildings should be avoided, as they can be difficult for disabled people to operate. Where door closers are required to comply with, for example, fire regulations, the door opening should be power assisted to reduce the physical effort required to operate the door.

Security

External doors should be designed so as to provide a secure barrier against unauthorised entry. An external door, particularly at the rear or sides of

buildings (out of sight), is obviously a prime target for forced entry. Solid hinges, locks and key bolts to a solidly framed door in a soundly fixed solid frame are the best security against forced entry. Insurance companies offer advice and may set minimum requirements for door types and especially the performance of locks. Advice is also available from the police via their Secure by Design initiative.

Privacy

Doors should serve to maintain privacy inside rooms to the same extent that the enclosing walls or partitions do. For visual privacy doors should be as obscure as the walls or partitions. For acoustic privacy, doors should offer the same reduction in sound as the surrounding walls or partitions, should be close fitting to the door frame or lining and be fitted with flexible air seals all round. These seals should fit sufficiently to serve as an airborne sound barrier, and to improve the air tightness of the door. For internal rooms, where air tightness is not a consideration, seals can make doors difficult to open and care is required in deciding when and where to use the appropriate type of seal.

Strength, stability and durability

A door assembly should be strong enough to sustain the conditions of use without undue damage. The suggested tests are for resistance to damage by slamming shut or open, heavy body impact, hard body impact, torsion due to the leaf being stuck in the frame, resistance to jarring vibrations and misuse of door handles. Categories of duty related to use are suggested, from Light Duty (LD) through Medium Duty (MD) and Heavy Duty (HD) to Severe Duty (SD). A door should be easy to open, close, fasten or unfasten and should stay closed when shut.

Dimensional stability

A door should not bow, twist or deform in normal use to the extent that its appearance is unacceptable or it is difficult to open or close. The dimensional stability of wood, metal and plastic doors is affected by temperature and humidity differences. Wood doors are affected mainly by temperature and humidity, metal doors by temperature, and plastic by thermal and hygrothermal movements.

Bow in doors is caused by differences in temperature and humidity on opposite faces, which may cause the door to bow with a curvature that is mainly in the height of the door and should not exceed 10 mm. Twist is caused, particularly in panelled wood doors, where movement of the spiral grain, due to changes of moisture content, causes one free corner to move away from the frame. This should not exceed 10 mm.

Weather resistance

As a component part of an external wall a door should serve to exclude wind and rain depending on the anticipated conditions of exposure described for windows. Careful detailing of the door jambs and inclusion of weatherstripping will help to reduce or eliminate draughts and assist with the conservation of heat. Laboratory tests on doors show that external doors, particularly those opening inwards, are more susceptible to water leakage than windows. It is difficult to design an inward opening external door that will meet the same standards of water tightness that are expected of windows, without the protection of some form of porch or canopy. For maximum water tightness a door will need effective weatherstripping, which will to an extent make opening more difficult, and a high or complex threshold which may obstruct ease of access.

Fire safety

Doors may serve two functions in the event of fire in buildings: first as a barrier to limit the spread of smoke and fire and secondly to protect escape routes.

To limit the spread of fire it is usual to divide larger buildings into compartments of restricted floor area by means of compartment floors and walls. Where doors are formed in compartment walls the door must, when closed, act as a barrier to fire in the same way as the walls. For this purpose doors must have a notional integrity, which is the period in minutes that they will resist the penetration of fire. Approved Document B gives provisions of tests for fire resistance of doors, with minimum requirements in minutes for the integrity of doors. These are usually stated as, for example FD 20, being a provision of 20 minutes minimum integrity for a fire door (FD).

There should be adequate means of escape from buildings in case of fire, to a place of safety outside, which is capable of being safely and effectively used at all times. To meet this basic requirement it is usual to define escape routes from most buildings along corridors and stairways that are protected by fire barriers and doors from the effects of fire for defined periods. This latter function of a fire door is described as smoke control. The majority of doors along escape routes will need to serve as fire doors to resist spread of fire and to control smoke.

Resistance to the passage of heat

Operation, strength, stability and security have always held more importance in the construction of a door than resistance to heat transfer. With increased thermal insulation of the external fabric the importance of fitting thermally efficient door sets has grown. There are two considerations. First, the resistance to heat transfer by both door and frame and second the air leakage between door and frame and between frame and wall. The current thermal resistance requirement for doors is 2.2 W/m^2 K, where the area of window, doors and roof lights does not exceed 25% of the total floor area. Doors, even when closed, can be a major source of heat loss. Most doors in current use are poor thermal
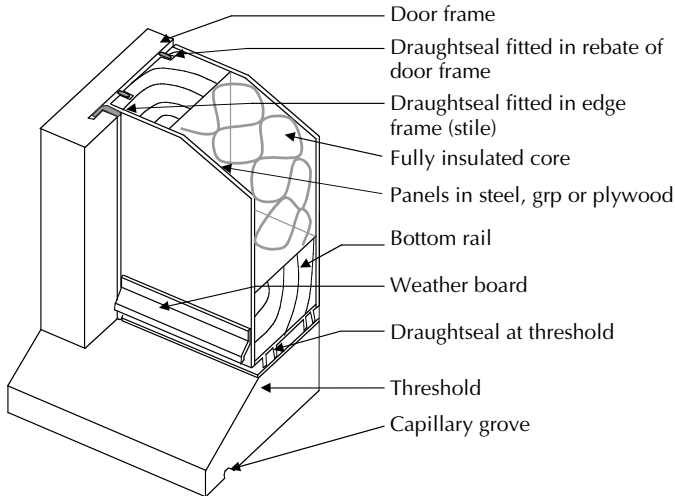
Figure 8.2   Typical construction of an insulated door.

insulators. A typical single skin timber panel external door has a U value of $3.0 \, W/m^2 \, K$; such a door would suffer the same heat loss as $40 \, m^2$ of well-insulated wall or $26 \, m^2$ of wall at the current Building Regulations. Houses that are classed as particularly energy efficient use doors with U values of $0.5 \, W/m^2 \, K$ or less (BRECSU, 1995a). An example of door construction, which could have a U value of less than $0.5 \, W/m^2 \, K$ is shown in Figure 8.2.

Airtightness
Doors and windows are particularly susceptible to air leakage. All doors and windows, whether uPVC, metal or wood, expand and contract due to temperature differences between the internal and external environments and seasonal changes. Over time the casements and frames distort, the fittings wear and the effectiveness of seals may be reduced. To maintain the air tightness of windows, weather stripping that is capable of retaining a seal if the door distorts should be used.

Resistance to the passage of sound
A door should afford reduction of sound for the sake of privacy and for those functions, such as lecture rooms, where the noise level is of importance. Generally the heavier a door (the greater its mass) the more effective a barrier it is in reducing sound transmission. A solid panel door is more effective than a flimsy hollow-core flush door. To be effective as a sound barrier a door should be fitted with air seals all round as a barrier against airborne sound. Figure 8.3 shows threshold seals that can be used to improve insulation against airborne sound.
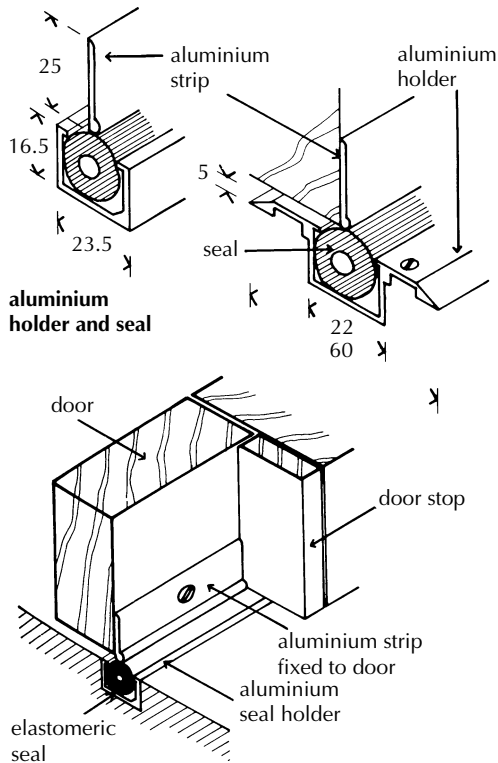
Figure 8.3   Threshold seal for internal doors.

Aesthetics

Given our high level of interaction with doors and door openings it is important that the aesthetic qualities of the door are considered. This is very much a personal consideration and is not addressed in this book, other than to say that choice of door and ironmongery will be influenced by personal taste as well as by functional and performance requirements.

8.2 Door types

Doors are supported in openings (doorways) on hinges as side hung, on pivots as double swing and on tracks as sliding or folding doors as illustrated in Figure 8.4. The side on which the door is hung is termed its hand or handing. Describing doors as opening in, or out, and as either left hand, right hand or clockwise, anti-clockwise doors tends to cause confusion and should be avoided.

❑ Hinged, single swing, side hung doors are for frequent use between rooms and between rooms and corridors or landings.

side hung
single leaf
single swing door

side hung double leaf
single swing door

side hung double leaf
double swing door

side hung
single leaf
double swing door

door
track

single leaf
straight sliding door

floor
channel
for guide

door
track

double leaf
straight sliding door

floor
channel
for guide

door
track

four leaf straight
sliding door

floor
channels
for guide

door track fixed
to soffit of opening

centre folding sliding door
with two half and two
full leaves

floor track
for door guide

door track

edge folding sliding door
with four leaves

door leaves
fold back to wall

floor track
for door
guide

Figure 8.4   Hinged, sliding and sliding folding doors.
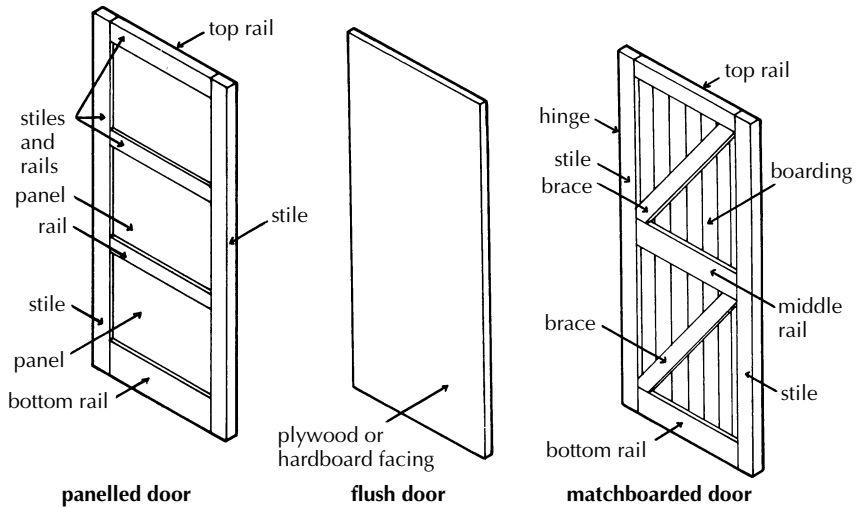
Figure 8.5   Wood doors.

❑ Hinged and pivoted side hung, double swing doors are for frequent use along corridors to accommodate two-way foot traffic.
❑ Sliding and sliding folding doors hung on overhead track are for occasional use in openings between rooms to convert single rooms into larger double rooms.
❑ Combinations of single swing, double swing and sliding and folding doors may be used for specific purposes.

Timber door classification
Timber doors may be classified as (Figure 8.5):

❑ Panelled doors
❑ Glazed doors
❑ Flush doors
❑ Matchboarded doors

The traditional door is formed from solid softwood or hardwood members framed around panels. This construction has been in use for centuries with little modification other than in changes in jointing techniques due to machine assembly and the use of substitute materials for wood.

Panelled doors

Panelled doors are framed with stiles and rails around a panel or panels of wood or plywood. Because the door is hinged on one side to open, it tends to sink on the lock stile. The stiles and rails have to be joined to resist the tendency
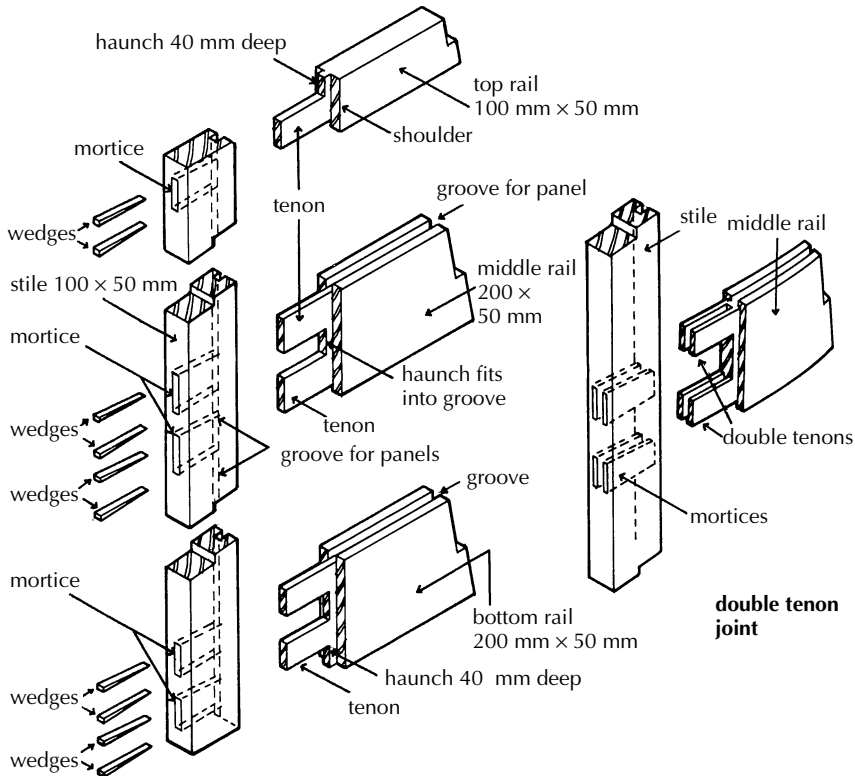
Figure 8.6   Mortice and tenon joint.

of the door to sink and the two types of joint used are a mortice and tenon joint (Figure 8.6) and a dowelled joint (see Figure 8.8).

Mortice and tenon joint
This is a strong joint used to frame members at right angles in joinery work. Figure 8.6 shows the stiles and rails of a panelled door before they are put together and glued, wedged and cramped around the panels, which are not shown.

Haunched tenon
The tenons cut on the ends of the top rail cannot be as deep as the rail if they are to fit into enclosing mortices, so a tenon about 50 mm deep is cut. It is possible that the timber of the top rail may twist as it dries, so to prevent this happening a small projecting haunch is cut on top of the tenon, which fits into a groove in the stile.

  Two tenons are cut on the ends of the middle and bottom rails. It would be possible to cut one tenon the depth of the rails but the wood around the

mortice might bow out and so weaken the joint. Also a tenon as deep as the rail might shrink and become loose in the mortice. To avoid this, a tenon should not be deeper than five times its thickness, hence the use of two tenons on the middle and bottom rails. Double tenons are sometimes cut on the ends of the middle rail as illustrated in Figure 8.6. The purpose of these double tenons is to provide a space into which a mortice lock can be fitted without damaging the tenons.

Glueing, wedging and cramping

The word cramp describes the operation of forcing the tenons tightly into mortices. The members of the door are cramped together with metal cramps, which bind the members together until the glue in the joints has hardened. Before the tenons are fitted into the mortices both tenon and mortice are coated with glue. When the members of the door have been cramped together, small wood wedges are knocked into the mortices top and bottom of each tenon. When the glue has hardened the cramps are released and the projecting ends of tenon and wedges are cut off flush with the edges of the stiles.

Mortice and tenon joints may, over time, become loose as the door timber shrinks, and the door will lose shape. To prevent this, panelled doors are sometimes put together with pinned mortice and tenon joints. The mortices and tenons are cut in the usual way and holes are cut through the tenons and the sides of the mortices, as illustrated in Figure 8.7. The tenons are fitted to the mortices, and wooded pins (dowels) of 13 mm diameter are driven through both mortice and tenon. Because the holes in the tenons and mortices are cut slightly off centre the pins, as they are driven in, draw the tenons into the
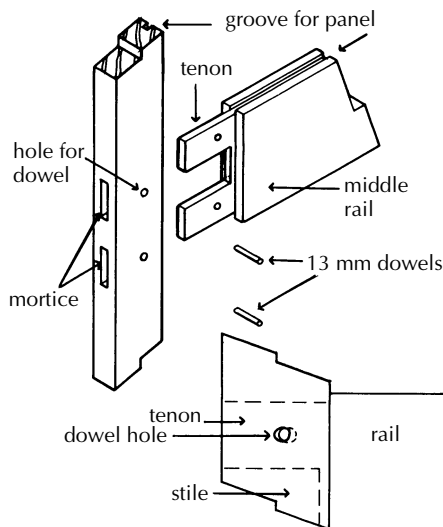
Figure 8.7   Pinned mortice and tenon.

mortices. Pinned mortice and tenon joints are glued and wedged. This joint should be used for heavy panelled doors.

The economic advantage of woodworking machinery cannot be exploited to the full in the cutting, shaping and assembly of mortice and tenon joints. It is practice, therefore, to use a jointing system better fitted to woodworking machine operations in the cutting and assembly of mass-produced doors.

Dowelled joints

With the dowelled joint which is used to frame standard size panelled doors, continuous grooves are cut in the edges of the stiles and rails to take the panels and continuous, protruding haunches on the ends of rails as illustrated in Figure 8.8. The haunches on the ends of the rails fit into the grooves cut in the edges of stiles to secure and level the members. By this arrangement the cutting of grooves and haunches are continuous operations suited to the use of woodworking machinery. Wood, plywood or wood particleboard, plain panels are cut to size to fit into the grooves cut in the stiles and rails. With improvements in glues, this type of joint will strongly frame the members of a panelled door.
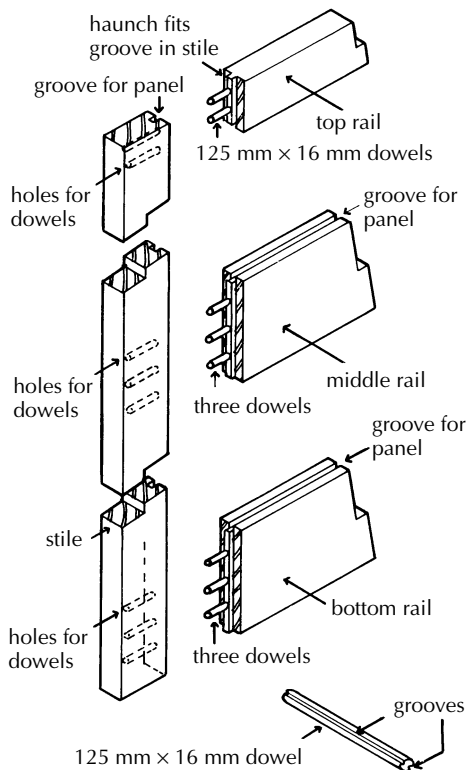
Figure 8.8   Dowelled joints.

22 mm × 3 mm
tongue in grooves
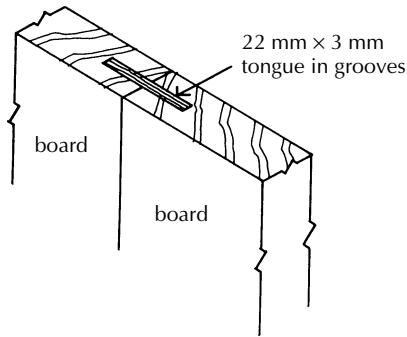
board

board

Figure 8.9   Boards through tongued to form panels.

Panels – avoiding shrinkage cracks

The comparatively thin wood from which panels are made will in time shrink due to loss of moisture, particularly in heated buildings. As drying shrinkage of wood occurs mainly across the long grain, panels may develop vertical cracks. To minimise shrinkage cracking of wood panels it is practice to make panels that are more than 250 mm wide from boards that are tongued together. The term 'tongued' describes the operation of jointing boards by cutting grooves in their edges into which a thin tongue of wood is cramped and glued as illustrated in Figure 8.9. By using boards rather than one panel, shrinkage cracking may be avoided.

To avoid shrinkage of panels, plywood may be used. Plywood is made from three, five, seven or nine plies of thin sheets of wood firmly glued together, so that the long grain of one play is at right angles to the long grain of the plies to which it is bonded. The opposed long grain of the plies strongly resists shrinkage cracking. Three-ply wood 5 or 6.5 mm thick is generally used for panels.

Securing panels

The traditional method of fixing and securing panels in doors is to set them into the grooves cut in the edges of the stiles and rails. To allow for drying shrinkage and any framing movements there should be a clearance of 2 mm between the edges of the panels and the bottom of the grooves in which they are set.

The advantages of setting panels in grooves in the framing members is that the panels are securely fixed in place and that shrinkage and movement of the frame will not cause visible cracks to open up around panels.

Panels set in grooves in stiles and rails with square edges may have a plain, unfinished look. To improve the appearance of a panelled door, mouldings are cut on the edges of the stiles and rails around panels as illustrated in Figure 8.10. For this finish the ends of rails have to be scribed to fit around the moulding
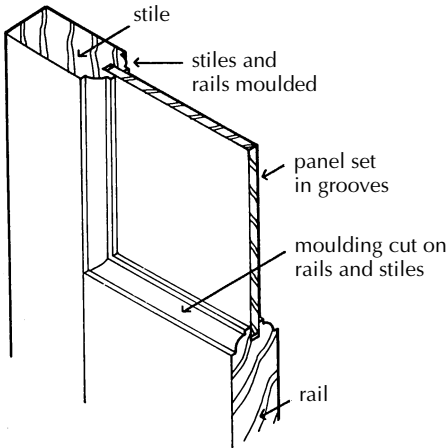
Figure 8.10   Framing moulded around panels.

cut on the stiles. The term 'scribed' describes the operation of cutting the wood to shape to fit closely around the moulding, which is cut continuously down the length of the stile.

A cheaper method of giving the appearance of mouldings around panels is to nail moulded timber beads around each panel as illustrated in Figure 8.11. Owing to the drying shrinkage, cracks may open up between the beads and the framing and panels of doors.

Panelled doors

The traditional panelled door was constructed with four or six panels with central framing members, termed muntins, tenoned to rails as illustrated in
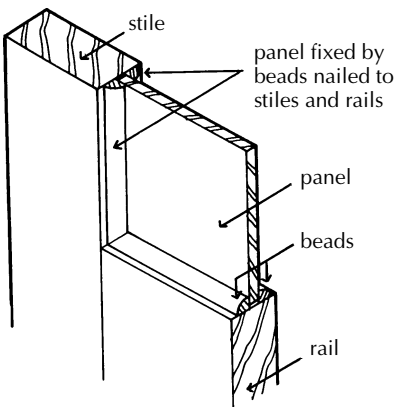
Figure 8.11   Planted moulding.
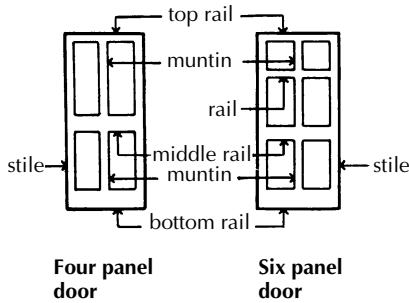
Figure 8.12   Traditional panelled doors.

Figure 8.12. The advantage of this arrangement is that the width of the panels is limited to reduce the possibility of shrinkage cracks and the shape of the panels emphasises the verticality of the door.

For the sake of economy in using woodworking machinery and a change in fashion, standard, panelled wood doors are made without muntins with panels between the stiles of the framing as illustrated in Figure 8.13.

Doors with raised panels
For appearance sake, entrance doors and doors to principal rooms in both domestic and public buildings are often made more imposing and attractive by the use of panels that are raised, so that the panel is thicker at the centre than at the edges. Such doors are often made of hardwood, which is finished to display the colour and grain of the wood by polish or French polish.

To avoid the ends of tenons showing on the edges of the door, it is practice to use stub tenons, which are secured with foxtail wedges, as illustrated in Figure 8.14. The foxtail wedges fit to saw cuts in the ends of the stub tenons so that when the tenon is cramped into the mortice the wedges spread the tenon to bind to the mortice. This type of joint, which has to be very accurately cut, makes a sound joint. As an alternative, dowelled joints may be used. Raised
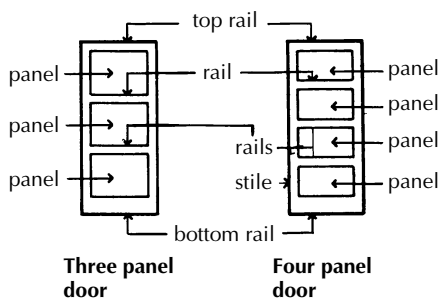
Figure 8.13   Standard interior panelled doors.
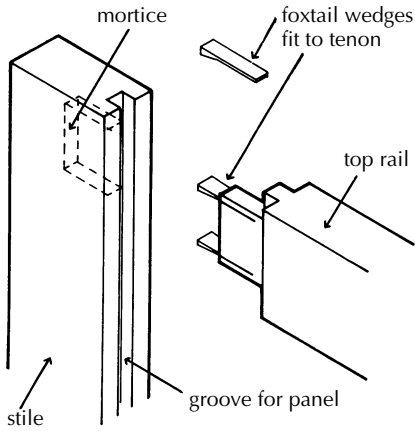
Figure 8.14   Foxtail wedges.

panels are either bevel raised, bevel raised and fielded, or square raised and fielded.

Bevel raised panels
These are cut with four similar bevel faces each with a shallow rise from the edges of the panel to a point with square panels and ridge with rectangular panels as illustrated in Figure 8.15A.
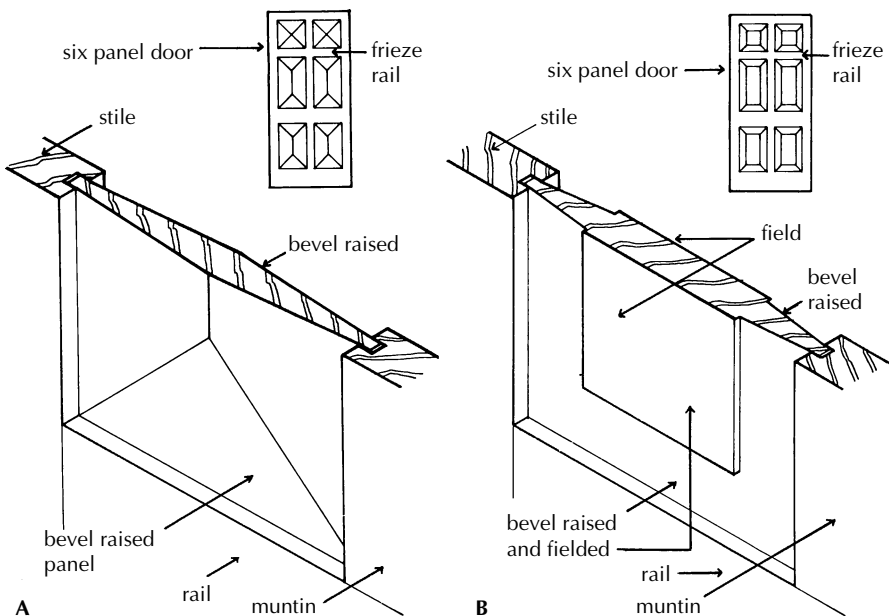
Figure 8.15   (A) Bevel raised panels. (B) Bevel raised and fielded panels.
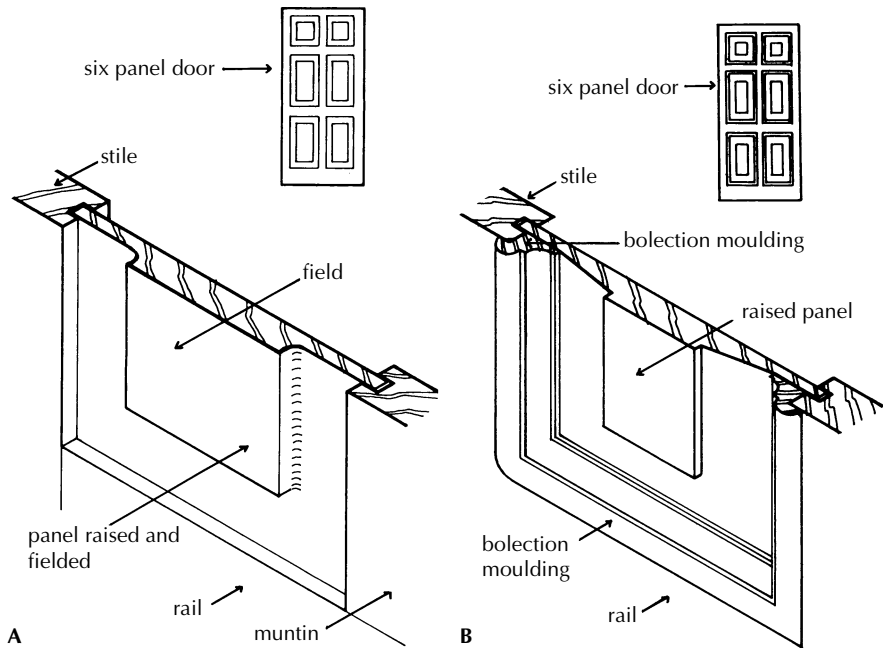
Figure 8.16   (A) Raised and fielded panels. (B) Bolection moulding.

Bevel raised and fielded panels
These are cut with four similar bevel faces rising from the edges of the panel to a flat surface, termed the field, illustrated in Figure 8.15B. At the field the panel is either as thick as or slightly less thick than the stiles. The proportion of the fielded surface to the whole panel is a matter of taste.

Raised and fielded panel
The panel, which is of uniform thickness around the edges, is raised to a flat field at the centre with a shallow sinking as illustrated in Figure 8.16A, the field being square or rectangular depending on the shape of the panel. Panels may be raised on both sides, as shown in Figure 8.15A, or on one side only, as illustrated in Figure 8.16A.

Bolection moulding
A bolection moulding is planted (nailed) around the panels of a door for the sake of appearance. The moulding is cut so that when it is fixed it covers the edges of the stiles and rails around the panel for the sake of empha-sis, as illustrated in Figure 8.16B. This particular section of wood moulding may be used with both raised and fielded panels on one or both sides of a door.
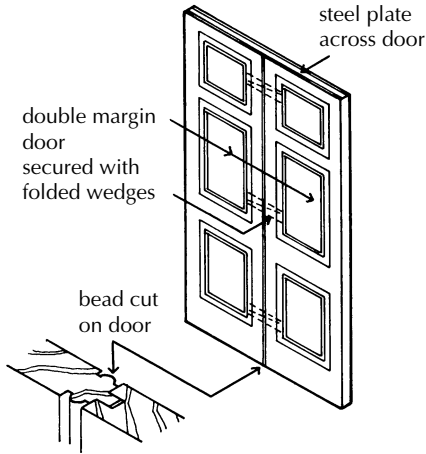
Figure 8.17   Double margin door.

Double margin door

A wide panelled door may be constructed as one door or as two doors hinged to meet in the middle. A single door would tend to look clumsy with oversize panels, whereas two doors would each be too narrow for comfortable access when only one leaf is opened. As a compromise such doors can be made up as if they were two doors with the two doors fixed together and acting as a single door as illustrated in Figure 8.17.

Solid panels – flush panels

Solid panel doors are constructed with panels as thick as the stiles and rails around them for strength, security, aesthetics or where the door acts as a fire check door.

These doors are usually constructed of hardwood, such as oak. The solid panels are tongued to grooves in the stiles and rails and are either cut with a bead on their vertical edges or with a bead all round each panel for appearance sake. Timber shrinks more across than along its long grain and because the long grain in these panels is arranged vertically the shrinkage at the sides of the panels will be more than at the top and bottom. For this reason beads are cut on the vertical edges of the panels to mask any shrinkage cracks that might appear, as illustrated in Figure 8.18.

Double swing doors

Double swing doors are used at the end of and along busy corridors and as shop entrance doors for the convenience of two-way foot traffic. As it is easier and quicker to push than pull a door open, this type of door is used for the convenience of passing through the doorway in either direction. To avoid the

100 mm × 50 mm top rail

solid panel
butts to rails

200 mm × 50 mm
middle rail

bead on
panel

stile

200 × 50 mm
bottom rail

bead

A Door with solid panels bead butt

bead fixed
in groove

top rail

bead cut
on rail

bead on
solid panel

100 mm × 50 mm
stile

bottom
rail

**B Door with solid panels finished
bead flush**
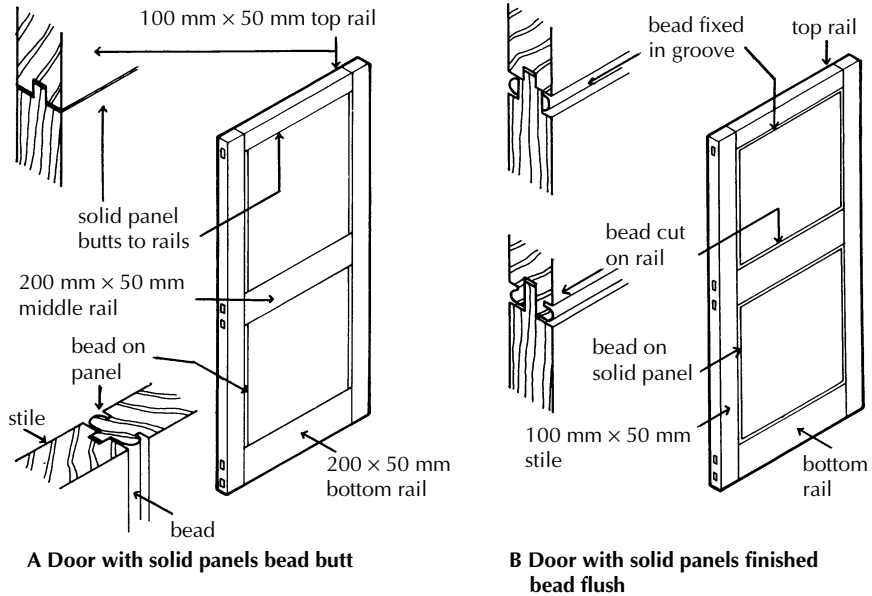
Figure 8.18   (A) Solid panels bead butt. (B) Solid panels bead flush.

danger of the door being pushed simultaneously from both sides these doors are constructed with either a glazed top panel or they are fully glazed.

To allow for the double swing action of the door, the vertical edges of the door are rounded to rotate inside a rounded rebate in the timber door frame as illustrated in Figure 8.19. The door is either hung on double action hinges designed to accommodate the double swing or supported by double action floor springs and a top pivot as illustrated in Figure 8.19. The door is supported by a shoe that fits to the spindle of the double action spring, which fits into a box set in the floor. A top plate, which is screwed to the spring box, finishes flush with the floor. A bearing plate, fixed to the top of the door, fits to a pin protruding from a plate fixed to the door frame. Because of the necessary clearance gaps around the door, it provides poor thermal and acoustic resistance.

Sliding doors
Sliding doors are designed mainly for occasional use to provide either a clear opening or act as a barrier between adjacent rooms or spaces to accommodate change of use or function and where it is necessary to avoid the obstruction caused by a hinged leaf. Sliding doors can only be used where there is room for the door or doors to slide to one or both sides of the opening. These doors may slide as two leaves, one to each side or as one leaf, to one side of the opening.
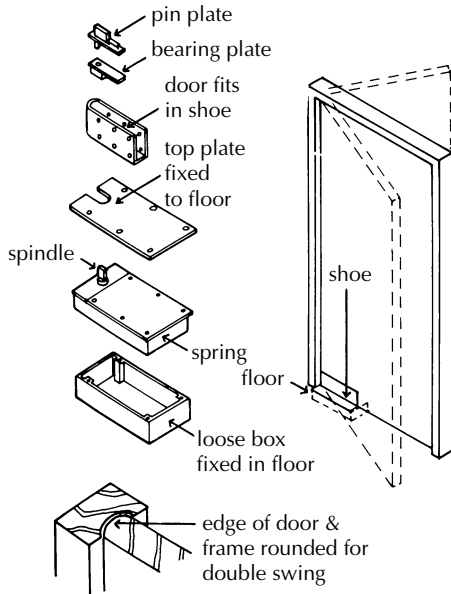
Figure 8.19   Double swing door.

Sliding folding doors

Sliding folding doors are used to separate rooms or spaces where it is convenient to be able to join the two rooms or spaces for their full width each side of the opening. Because of the folding sliding action the hinged leaves of the door can slide and fold back against a wall to occupy little space. Sliding and sliding folding doors should be hung on an overhead track. An inverted 'U' shaped track is fixed to the overhead beam with brackets as illustrated in Figure 8.20. Hangers, in the form of a four-wheeled trolley, run in the overhead track and support the door leaves through brackets screwed to the doors.

At the bottom of the door a channel, set and fixed in the floor, acts as a guide to a pin or wheel fixed by brackets to the door. To maintain a reasonably easy movement of sliding doors it is necessary to keep the bottom guide track free from dirt that might obstruct movement and to keep the hangers reasonably oiled.

The door leaves of both sliding and sliding folding doors may be of either panelled or flush construction. The lighter the doors, the easier their movement and the heavier, the better they serve as a sound barrier.

Glazed doors

Doors with panels of glass or fully glazed are used to provide daylight into unlit spaces or to allow people to see through the door. A vision panel may

brackets at
600 mm to 900 mm
centres to
support track

steel track

four wheel
hanger

lining
to track

pendant bolt
pivots on hanger

door
leaf

brackets
screwed
to door

guide runs in
channel in floor
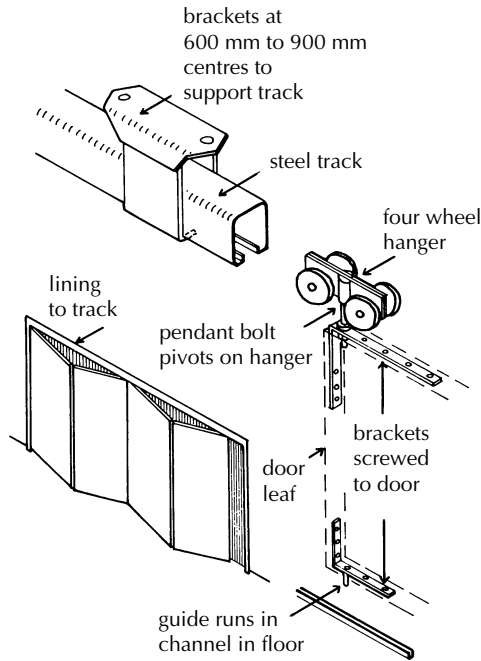
Figure 8.20   Sliding folding door.

prevent a person opening a door into the path of a person on the other side. Fully glazed doors fixed in an external wall serve as both door and window.

Glazed entrance doors, which stand within a glazed screen, should be clearly differentiated from the screen. Approved Document M requires a high contrast strip to be used on the top, bottom and sides of the door.

It is important that glazed doorways are easily recognisable since they can pose problems for people with impared sight. Approved Document M requires that fully glazed doors and screens are defined with 'manifestations' on the glass at two levels, 850 to 1000 mm and 1400 to 1600 mm above the floor, which can be seen from both the inside and outside. A manifestation takes the form of a logo, sign, image or decorative feature. The manifestation should be at least 150 mm high, providing a contrast strip.

Where glass doors are capable of being held open, they must be protected by a guard to prevent the leading edge causing a hazard, thus preventing people walking into the open door.

Purpose made glazed doors
A common form of traditional wood door for external use has glazed upper panels to admit daylight to halls. This door is framed as solid lower panels with upper glazed panels. The door may be framed as a normal panelled door
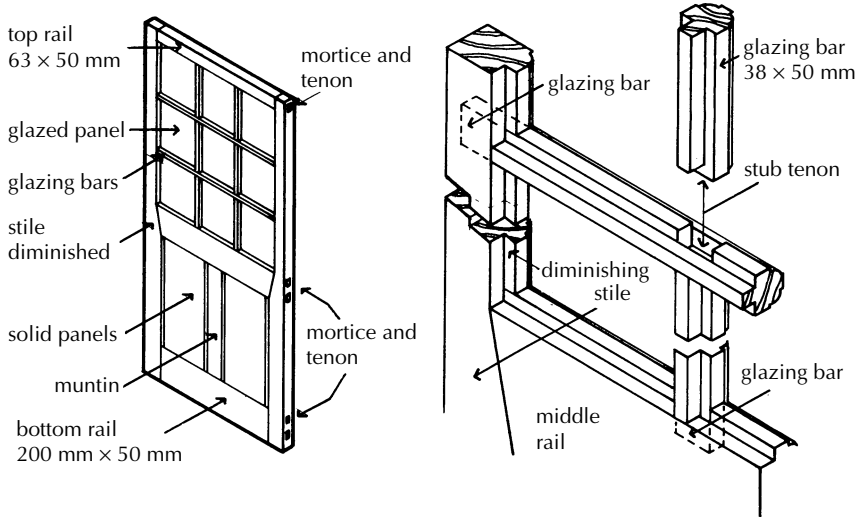
Figure 8.21   Glazed door with diminishing (gun stock) stiles.

with continuous width stiles or with diminishing stiles to provide a greater width for glazing as illustrated in Figure 8.21.

French casement

The traditional form of first floor window to many French and northern Mediterranean countries is in the form of a timber framed door, fully glazed as illustrated in Figure 8.22. The door is made with vertical and horizontal glazing bars as part of the framing. These doors serve as windows to the first
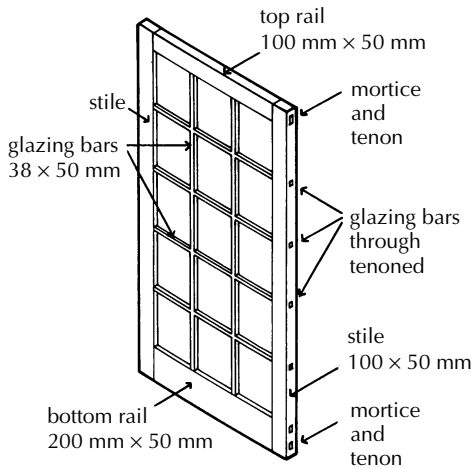
Figure 8.22   Casement door (French casement).
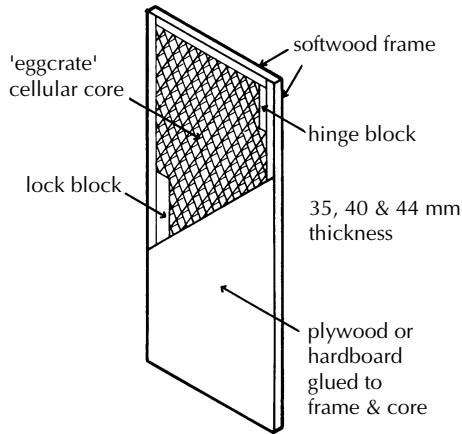
Figure 8.23   Cellular core flush door.

floor rooms and as doors, opening in, for access to balconies and ventilation during summer. Louvered timber shutters are hung externally to close over the window opening to exclude summer sun and provide ventilation.

Flush doors

A variety of flush doors are manufactured with plain flush faces both sides and fibreboard facings press moulded, often with comparatively shallow sinkings, to resemble the appearance of panelled doors.

Cellular core flush doors are made with a cellular, fibreboard or paper core in a light softwood frame with lock and hinge blocks, covered with plywood or hardboard facings glued to the frame and core both sides as illustrated in Figure 8.23. These lightweight doors are for light duty such as internal domestic doors. They do not withstand rough usage and provide poor acoustic privacy, security and fire resistance. They are mass-produced in a small range of standard sizes and are cheap.

Skeleton core flush doors are made with a core of small section timbers, as illustrated in Figure 8.24. The main members of this structural core are the stiles and rails, with intermediate rails as shown, as a base for the facing of plywood or hardboard. The framing core members are joined with glued, tongued-and-grooved joints. The door illustrated in Figure 8.24 has a skeleton core occupying from 30% to 40% of the core of the door. This is a light duty door suitable for internal domestic use. A similar skeleton core flush door with more substantial intermediate rails in the core, where the core occupies from 50% to 60%, is a medium duty door suitable for use internally in domestic and public buildings and for external use in sheltered positions. This somewhat more substantial door will withstand normal use and maintain its shape stability better than a cellular core door.
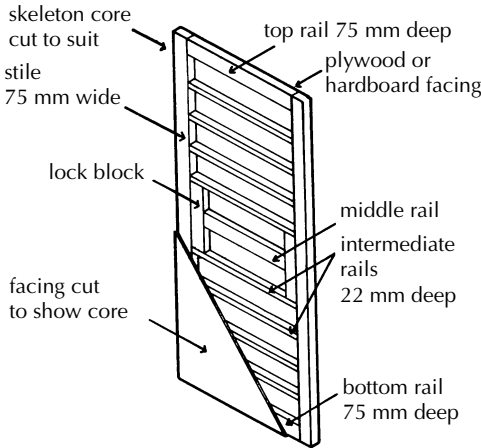
Figure 8.24   Skeleton core flush door.

Solid core flush doors are made with a core of timber, chipboard, flaxboard or compressed fibreboard strips. The solid core door illustrated in Figure 8.25 has a core of timber strips glued together, with plywood facings both sides glued to the solid core. The door is edged with vertical lipping to provide a neat finish. Because of the solid core these doors have somewhat better shape and surface stability and acoustic resistance than the cellular or skeleton core flush doors.

The chipboard, flaxboard and compressed fibreboard strip core doors are made with a solid core enclosed in a light timber frame to which hardboard or plywood is fixed. These solid core doors are more expensive than cellular core
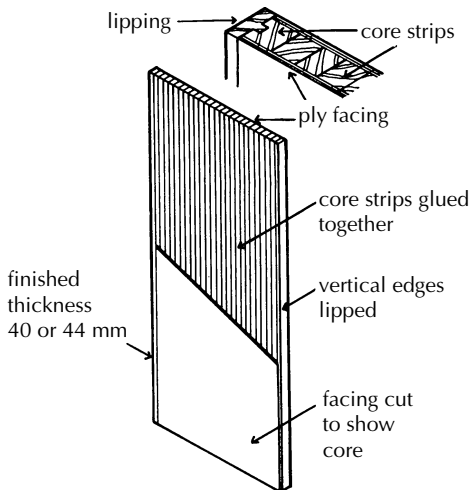
Figure 8.25   Solid core (laminate) flush door.

or skeleton core doors. Solid core flush doors may be used as fire doors with an integrity rating of 20 or 30 minutes.

Fire doors

Fire doors serve to protect escape routes and the contents and structure of buildings by limiting the spread of smoke and fire. Fire doors that are fixed for smoke control are only capable of withstanding smoke at ambient (surrounding) temperatures and limited smoke at medium temperatures by self closing devices and flexible seals.

Fire doors that are fixed as part of a fire compartment and as isolation of special risk areas should have a minimum fire resistance, for integrity only, of a period appropriate to that set out in Approved Document B.

Fire resistance integrity

To conform to international practice, doors and other non-loadbearing elements are no longer assessed for stability (resistance to collapse) or insulation. The test for integrity is assumed to include performance in regard to stability and insulation. The notation for fire doors is FD followed by the figure in minutes for integrity, as for example FD 20 or FD 30, and doors that serve for smoke control as for example FD 20S.

The performance test for fire doors that serve as barriers to the spread of fire is determined from the integrity of a door assembly or door set in its resistance to penetration by flame and hot gases. The test is carried out on a door assembly that includes all hardware, supports, fixings, door leaf and frame, representative of a door assembly that will be used in practice. Each face of the door assembly is exposed separately to prescribed heating conditions from a furnace, on a temperature–time relationship, to determine the time to failure of integrity. Failure of integrity occurs when flame or hot gases penetrate gaps or cracks in the door assembly and cause flaming of a cotton wool pad on the side of the assembly opposite to the furnace.

The door leafs illustrated in Figure 8.26 are constructed and faced to provide 30 and 60 minutes for integrity. The 30 minute skeleton core flush door is protected with plasterboard panels fixed to the skeleton core under the plywood or hardboard facings as illustrated in Figure 8.27. The 30 minute, solid core fire doors are protected with wood strips or high density chipboard covered with plywood or hardboard facings. The 60 minute, solid core fire doors are protected with compressed mineral wool or high density chipboard and hardboard or plywood facings. The flush, steel fire door to provide 60 minutes protection, shown in Figure 8.26 and illustrated in Figure 8.28, has welded sheet steel facings. The casing is pressed around steel stiffeners and a core of compressed mineral wool. The door is provided with intumescent seals and is hung on a pressed steel frame.
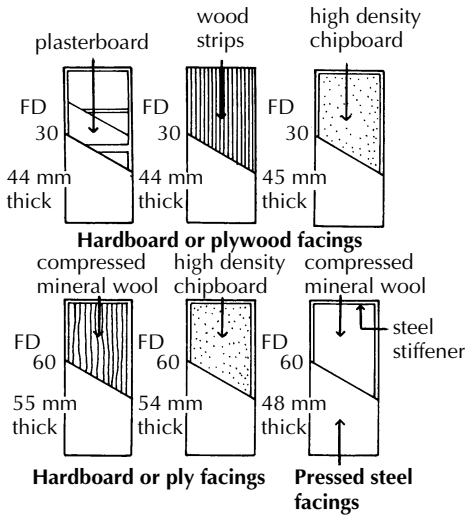
Figure 8.26   Fire doors.

A fire door should at once be easy to operate, serve as an effective barrier to the spread of smoke and fire when closed and be fitted with some effective self-closing device. For ease of operation there must be clearance gaps around the door leaf. These clearance gaps are effectively sealed when a door leaf closes into and up to the rebate in a door frame. Where a door leaf has distorted in use and when the leaf is distorted by the heat of a fire, then the leaf will no longer fit tightly inside the rebate of the frame and smoke and flame can spread through the gaps around the door leaf. As a barrier to the spread of smoke, flexible seals
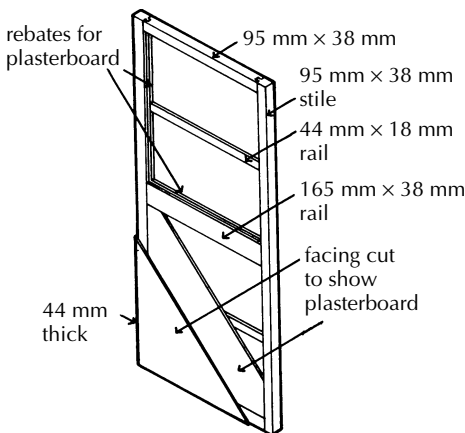
Figure 8.27   Standard half hour fire door.
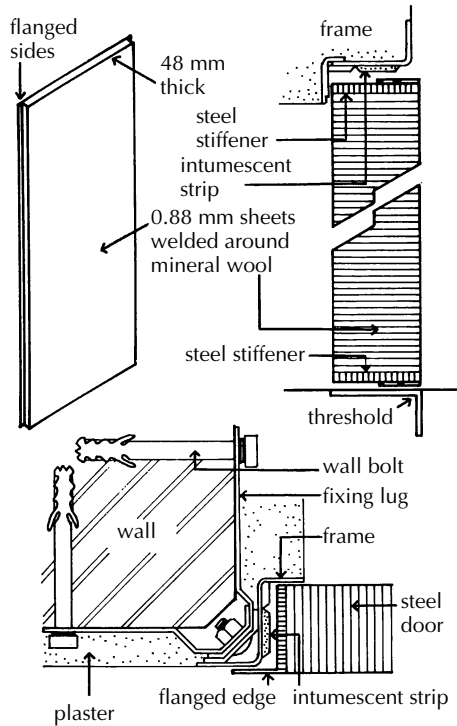
Figure 8.28   Flush steel fire door.

should be fixed between door leafs and frames and as a barrier to the spread of fire, heat activated (intumescent) seals should be fitted.

Smoke control door assemblies (FDS) that serve only as a barrier to the spread of smoke without any requirement for fire resistance, such as fire doors along an escape route, may be fitted in rebated frames or hung to open both ways. To provide an effective seal against the spread of smoke through gaps around these doors, flexible seals should be fitted.

Smoke control door assemblies that serve as a barrier to the spread of smoke and fire, such as doors leading to a protected escape route, should be hung in rebated frames and tested for a minimum integrity of 30 minutes against the spread of fire, and should be fitted with heat activated (intumescent) seals and flexible edge seals against the likelihood of the door leaf deforming.

Fire door assemblies fixed in compartment walls and to enclosures to special risk areas should be hung in rebated frames and tested for integrity for not less than 30 minutes or such period as detailed in Approved Document B, and should be fitted with the intumescent seals. The currently accepted minimum size of a softwood door frame for a fire door is 70×30 mm exclusive of a planted stop.
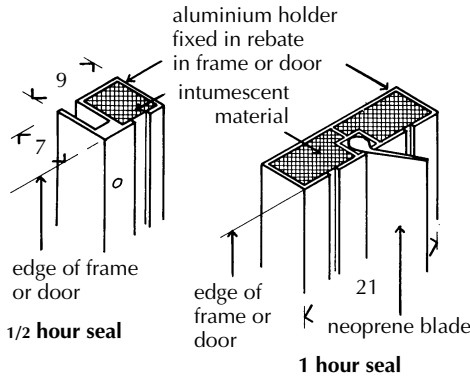
Figure 8.29   Intumescent fire seal.

Heat activated intumescent seals

An intumescent seal is made of a material that swells by foaming and expanding at temperatures between 140°C and 300°C. The intumescent seals illustrated in Figure 8.29 consist of aluminium holders inside which the intumescent material is held. The aluminium holders are fixed in a rebate to the edges of doors or to the door frames. When the temperature rises sufficiently the intumescent material inside the holders expands out through the vertical slots in the holder and effectively seals the door in the frame as a barrier to the spread of flame.

The neoprene blade shown in the 1 hour seal acts as a seal against smoke that occurs in the early stages of a fire before the intumescent material is sufficiently hot to expand. The intumescent seals shown in Figure 8.30 comprise a PVC casing in which the intumescent material is held. The seals are set in rebates in the edges of the door or in the rebate of the frame. As the temperature rises, the thermoplastic PVC casing gradually softens so that when the temperature has risen sufficiently, the intumescent material expands, ruptures the PVC casing and acts as a seal around the door.
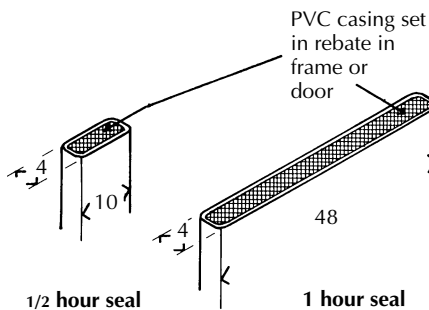
Figure 8.30   Intumescent fire seal.

fixed to
door
frame

closer surface
mounted

arm runs in
channel in
door frame

overhead closer
recessed in
thickness of
door
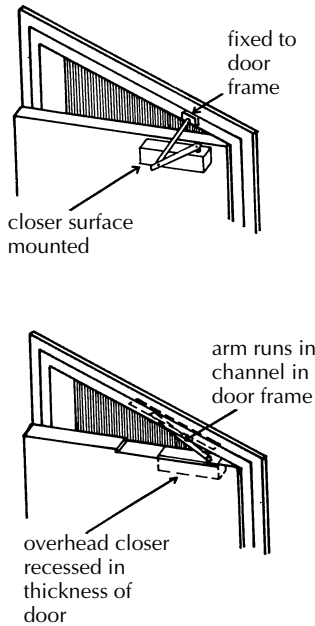
Figure 8.31   Overhead door closer.

For a fire door to be effective against smoke and the spread of fire it should, when not in use, be positively closed to the frame by some self-closing device. The door closers that are used are overhead door closers or one of the floor springs (Figure 8.19).

The overhead door closers illustrated in Figure 8.31 consist of a hydraulically operated cylinder in a metal casing that is either screwed to the door face or set in a housing in the top of the door leaf for appearance sake. Pivoted arms, one to the housing and one attached to the door frame, act to automatically close the door to the frame, after the door has been opened. Because these door closers are fixed to doors that are generally in frequent use they require regular maintenance if they are to serve their purpose.

The current requirement for fire doors is that complete door assemblies be tested in accordance with BS 476 and certified as meeting the recommendations of performance for integrity and noted, for example, as FD 20, FD 30 as satisfying the requirements for 20 and 30 minutes integrity respectively.

Matchboarded doors

These doors are made with a facing of tongued, grooved and V-jointed boards that are nailed to horizontal ledges, braces between ledges or to a frame. These relatively crude doors are sometimes described as 'matchboarded' doors

A ledged matchboarded door

150 mm

tongued, grooved
V-jointed boarding

ledge
100 mm × 32 mm

boarding nailed
to ledges

150
mm

ledge
150 mm × 32 mm

boarding on
external face
of door

ledge
150 mm × 32 mm

B ledged and braced matchboarded door

concrete lintel

100 mm × 75 mm
door frame

300 mm
tee hinge

ledge

brace
100 mm × 25 mm

matchboard

ledge
150 × 25 mm

brace
100 mm × 25 mm

300 mm
tee hinge

ledge
150 × 25 mm

Figure 8.32   (A) Ledged matchboarded door. (B) Ledged and braced matchboarded door.

because of the comparatively thin boards from which they are made (also known as 'cottage doors').

Ledged matchboard doors

Ledged matchboard doors are made by nailing matchboards to horizontal ledges, as illustrated in Figure 8.32A. The nailing of the boards to the ledges does not strongly frame the door, which is liable to sink and lose shape. This door is used for narrow openings only.

Ledged and braced matchboarded doors

Ledged and braced matchboarded doors are strengthened against sinking, with braces fixed between the rails at an angle to resist sinking on the lock edge (Figure 8.32B). The matchboarding is nailed to ledges and braces.

Framed and braced matchboarded doors

Framed and braced matchboarded doors are made by nailing matchboarding to a frame of stiles and rails that are framed with mortice and tenon joints with braces to strengthen the door against sinking, as illustrated in Figure 8.33. The boarding runs from the underside of the top rail, to protect the end grain of the boards from rain, and is carried down over both middle and bottom rails. To allow for the boards running over them the middle and bottom rails are less thick than the stiles to which they are joined with a barefaced tenon joint (Figure 8.34). This joint is used instead of the normal joint with two shoulders,
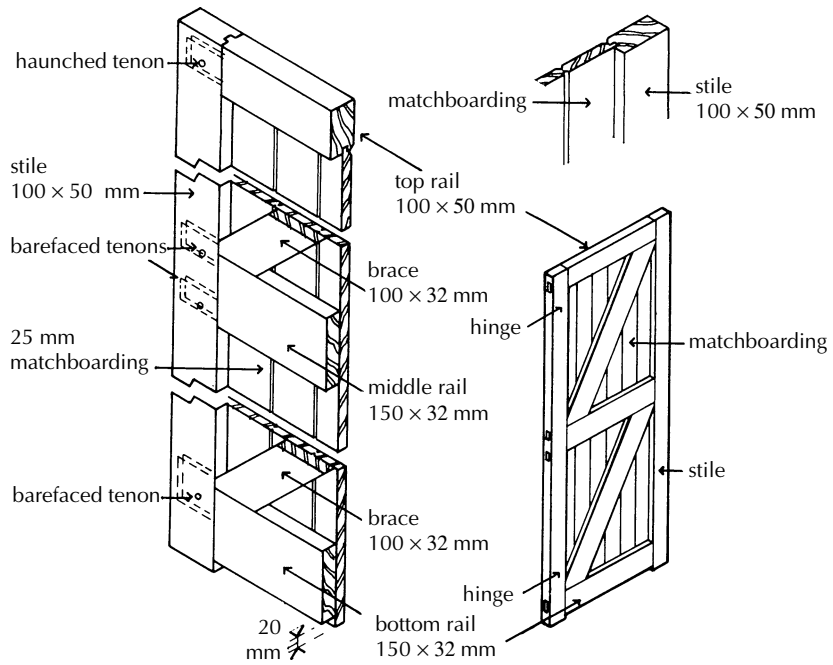
Figure 8.33   Framed and braced matchboarded door.
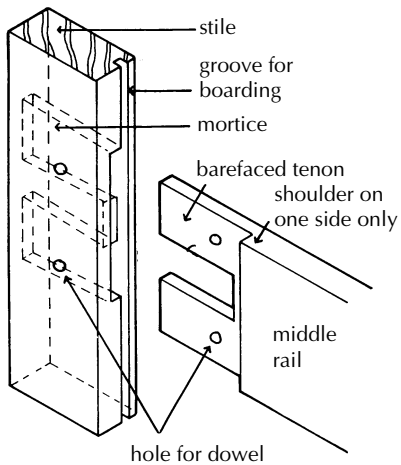
Figure 8.34   Barefaced tenon.

so that the tenon is not too thin. These doors are used for large openings to garages, factories and for entrance gates.

8.3 Door frames and linings

A door frame is made of timbers of sufficient cross section to support the weight of a door and to serve as a surround to the door into which it closes. The majority of door frames are rebated to serve as a stop for one way swing doors. The door frame is secured in the wall or partition opening to support external doors and heavier internal doors. Choice of frame or lining is to an extent a matter of appearance and convenience in fixing and the methods of masking the junction between plaster finishes and frames and linings.

Door linings are thin sections of wood or metal that are fixed securely in a doorway or opening as a lining around the reveal (thickness) of the wall or partition. A door lining which may not be substantial enough by itself to support the weight of a door will depend on its fixing to the wall or partition for support.

Door linings are generally used for internal doors in thin partitions where the width of the lining is the same as the thickness of the partition and wall plaster both sides. In this way the junction of the plaster and lining can be masked by an architrave and the door opening emphasised by the lining and architrave. Figure 8.35 illustrates a door frame and a lining.
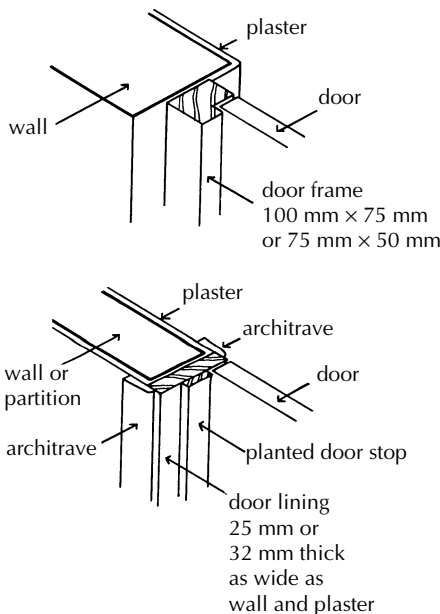
Figure 8.35   Door frame and door lining.

Door frames, commonly used for external doors and heavier internal doors, may not be as wide as the thickness of the wall in which they are fixed as illustrated in Figure 8.35. It is necessary, therefore, to run plaster finishes around the angle of the wall, into the reveal and up to the door frame. In time the junction between the plaster and frame will open up as an unsightly crack. A wood bead may be fixed to hide this potential crack. More substantial linings, or combinations of frames and linings, are used for panelled doors in walls that are one brick or more thick to combine the strength of a frame with the appearance of a lining.

Timber door frame

Timber door frames are assembled from three members for internal doors and four to most external doors. The members of the frame are two side posts, a head and a cill for external doors (where regulations do not prohibit an upstanding cill that would obstruct access). The members of the frame are usually cut with a rebate into which the door closes or a wood stop may be planted on a plain faced timber, as a door stop. Because the frame is made to carry the weight of the door by itself, the members are joined with mortice and tenon joints to provide a rigid joint that will maintain the frame true square as illustrated in Figure 8.36A. The haunched mortice and tenon joints between the posts and
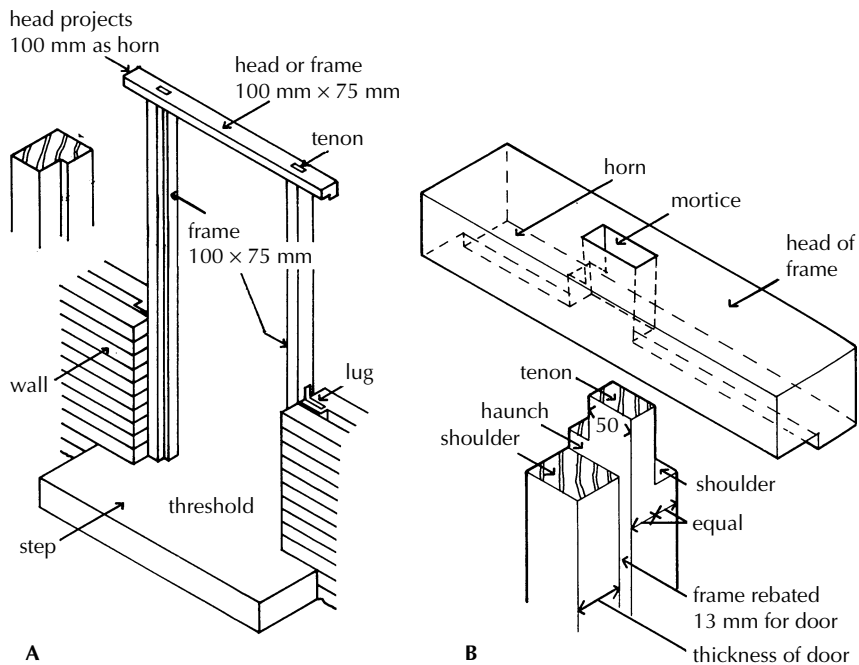
Figure 8.36   (A) Door frame. (B) Mortice and tenon joint.
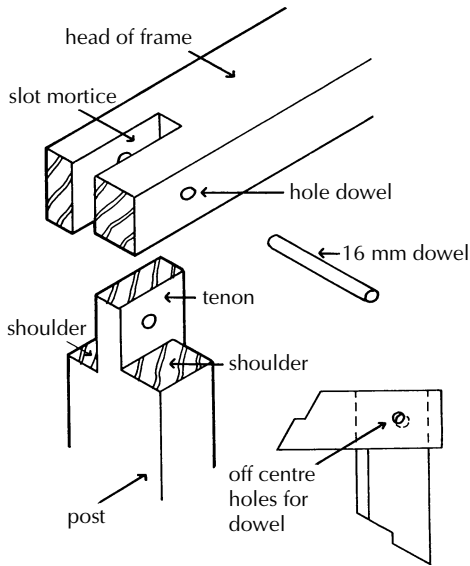
Figure 8.37   Slot mortice and tenon.

head of the door frame are formed as illustrated in Figure 8.36A and in detail in Figure 8.36B. The joint is formed by projecting the head of the frame some 100 mm each side of the posts as horns. These horns also provide a means of securing the frame by building them into surrounding brickwork where the frame is set at least $\frac{1}{2}$B back from the external face of the wall.

Where it is not convenient to build in horns when the door frame is fixed closed to the external face of a wall, the head is finished flush with the back of the posts. As it is not possible to form an enclosing mortice, a slot mortice and tenon joint is formed as illustrated in Figure 8.37. The tenon is secured in the slot mortice with a 16 mm dowel driven through the mortice and tenon.

Door frames to external walls may be built-in using fixing lugs. The frame is secured using fixing lugs that are built into horizontal courses of brickwork or blockwork as the walls are raised. The usual form of fixing lug used to secure wood window and door frames in solid walls is 'L' shaped, formed from galvanised steel. One tail of the lug is screwed to the back of the frame and the other is bedded in a horizontal brick or block course. Three lugs to each post are used. Providing these lugs, illustrated in Figure 8.36A, are solidly bedded in mortar they will adequately secure the frame in position.

A uPVC cavity closer and ties, illustrated in Figure 8.38, is designed to close the cavity of a wall and allow the cavity insulation to be carried up to the back of the closer, so that there is no thermal bridge around the openings and to provide
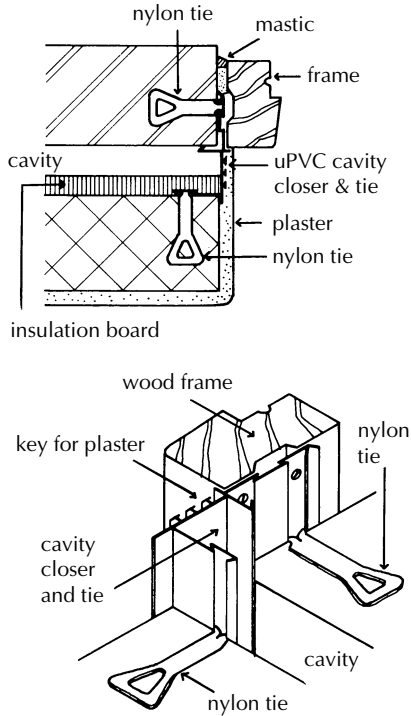
Figure 8.38   uPVC cavity closer and tie.

secure fixing for a door frame through nylon ties. The cavity closer is nailed to the back of the frame and the nylon ties are adjusted in slots for building into horizontal brick or block courses as the frame is built-in. Alternatively the cavity closer can be installed after the brickwork has been raised. The cavity closer can simply be installed into the cavity and secured by fixing (plug and screwed) to the wall reveals.

Most door frames are installed after the brickwork has been raised. In such cases the horns of the door frame will not be necessary and nylon or metal fixing lugs will be used to fix the frame in position.

Threshold
The threshold of a doorway or opening is the surface at the bottom of the opening that is level for internal doors and may be level or formed as a wood cill as part of the door frame. A level threshold may be formed for ease of access for the disabled who have need of a wheelchair. The considerable disadvantage of this is that there is no positive check to wind-driven rain that runs down the door face and will be blown in under the closed door.
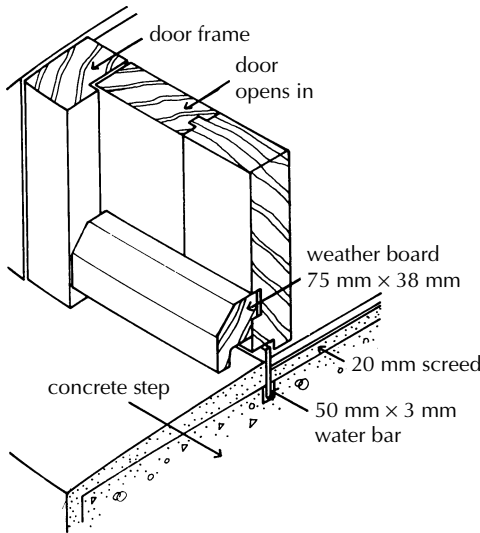
Figure 8.39   Water bar and weatherboard.

As a barrier to wind-driven rain running in under a door, a galvanised steel weather or water bar may be set in the threshold to stick up sufficiently above the level of the threshold so that when the door is closed it makes contact with the bar as a seal against the entry of rain as illustrated in Figure 8.39. To direct rainwater out from the door a weatherboard of timber or metal is often fixed to the bottom of the door. The disadvantage of the water bar is that it is of small section and not always obvious to the unwary who may trip over it.

It is common to hang external doors to open inwards. The disadvantage of an inward opening external door is that the rebate in the door frame, into which the door fits when closed, does not so positively act as a check to wind and rain as it does with an outward opening door. In exposed locations wind pressure may force an inward opening door away from the rebate to the extent that wind and rain may penetrate.

Traditionally external door frames were made up with a wood, usually oak, cill as part of the framing with the posts of the frame tenoned to mortices in the cill. The oak cill, which is of a wider section than the posts, is weathered and cut with a drip on its lower edge to throw water off as illustrated in Figure 8.40. The cill may be rebated as housing for the door when closed or finished flush with the floor. A metal weather bar is set in the sill to stick up sufficient to fit into a rebate cut in the underside of the door as a weathercheck. A wood weatherboard was usually fixed to the bottom of the outside of the door to throw rain out from the bottom of the door. Unless the protective paint film is well maintained over the door surface, the wood weatherboard will before long become saturated and rot. A range of aluminium sections is available for use as weatherboards.
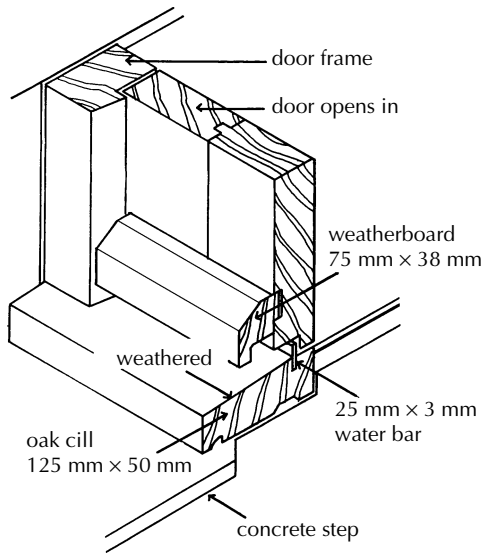
Figure 8.40   Oak cill.

Weatherstripping

As a check to wind-driven rain and draughts of cold outside air that penetrate clearance gaps around external doors it is practice today to fit weatherstripping around doors to limit damage caused to wood doors by rain and heat loss to cold air. The two systems of weatherstripping that are used are flexible seals fixed towards the inside face and compression seals fixed up to the outside face of doors.

Flexible seals are made from PVC or synthetic rubber in the form of a strip for housing in the frame from which a flexible blade makes contact with the edges of the door. The seal may be fitted into an aluminium channel holder, which is fixed into a groove cut in the frame. The flexible seal does not make it difficult to open or close the door, but is sufficiently resilient to make positive contact with the closed door.

The members of the door frame and door illustrated in Figure 8.41 are cut with rebates to form a drainage channel up to the outer face of the flexible seals. This small channel serves the purpose of drainage channel and to reduce wind pressure on the flexible seal. The synthetic rubber seals are similar to those described and illustrated for use with wood casement windows.

Compression seals consist of hollow ball section strips of synthetic rubber in an aluminium alloy or plastic holder. The holders are screwed or pinned to the head and posts of the door frame so that the elastic seal presses against the closed outside of the door as a weather seal. The bottom edge of the door is sealed by a holder, fixed to the door, in which an elastic bulb presses on an aluminium alloy threshold strip fixed to the cill as illustrated in Figure 8.42.
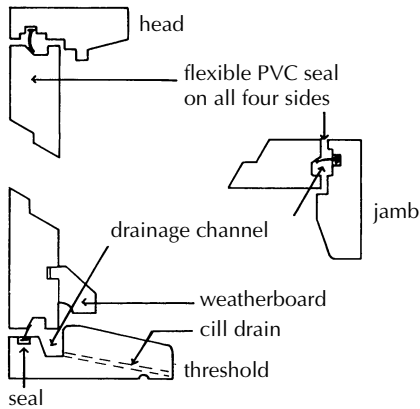
Figure 8.41   Inward opening external door with weather strips.

Unlike the flexible blade weatherstripping, these compression seals and their holders are visible, which may be unacceptable to some.

Both the flexible PVC blade strip and the compression seal bulb will after some years lose resilience and be less effective as seals. They should be replaced
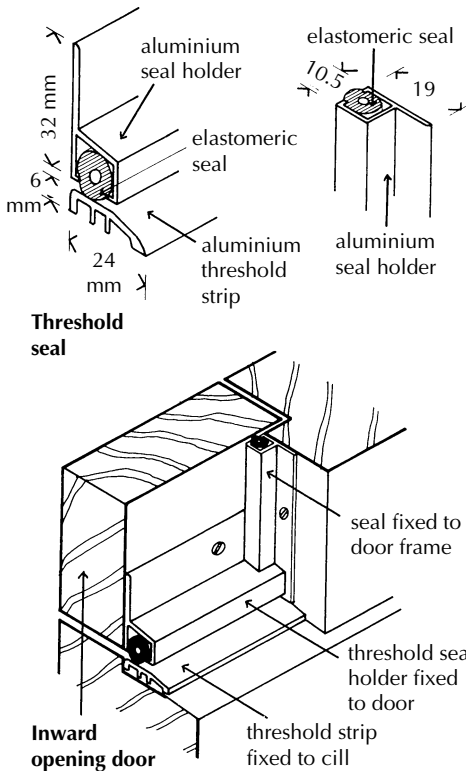
Figure 8.42   Threshold and side weather seal to inward opening external door.
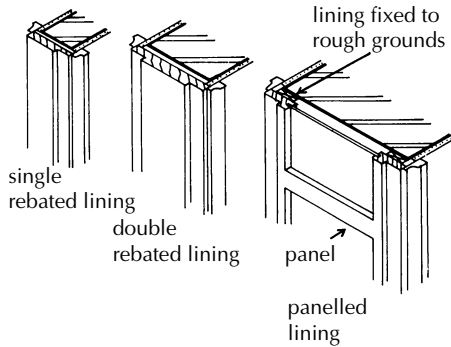
Figure 8.43   Door linings.

from time to time. When regular painting of doors and frame is carried out care should be taken to avoid painting over the blade seal and the compression seal as a dried, painted film will make them less effective. As an alternative to the compression seals illustrated in Figure 8.42, one of the self adhesive weatherstrips may be used.

Wood door linings

Wood door linings (door casings) may be plain and rebated or plain with planted stops, double rebated for appearance sake or panelled as illustrated in Figure 8.43. Plain linings with either a rebate or a planted stop are used for light doors in thin partitions, double rebated linings for thicker brick or block partitions and panelled linings for heavier panelled doors in thicker walls or partitions.

Linings are fixed in position in the door opening before plastering to walls is carried out, so that the finished plaster level is flush with the edges of the lining. The linings are nailed to rough wood grounds. Rough grounds are sections of plain sawn wood that are nailed to the surrounding brick or block partition to provide a level fixing to which the lining is nailed. The purpose of this is to avoid damaging the lining by driving large nails through the lining to find a fixing in the brick or block partition.

To provide a secure fixing for all but very narrow wood architraves around doors it is practice to fix rough, wood grounds each side of the lining. In some cases grounds may be used by plasterers as a guide for the finish of the plaster. Linings are cut to the overall thickness of partitions and the thickness of plaster both sides. Plain linings are usually cut from timber 47 or 54 mm thick for rebated linings and 31 or 38 mm thick for linings with planted (fixed) stops. Figure 8.44 is an illustration of a plain lining with planted stops fixed to a partition. The sides of the lining are jointed to the head with a tongued and grooved joint to secure the three sections in position.
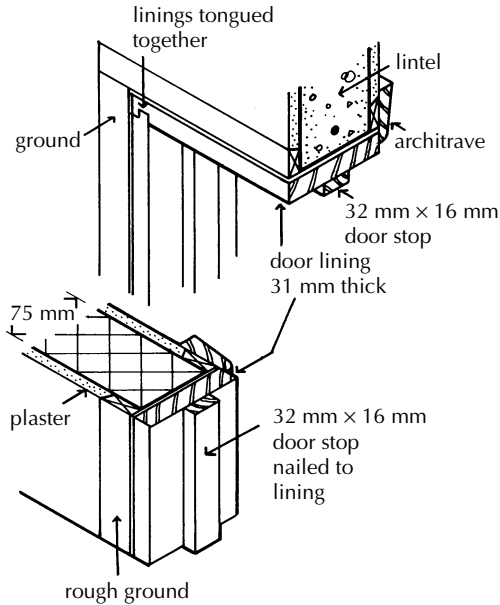
Figure 8.44   Door linings.

Standard door frames and linings

Door manufacturers offer a range of standard frames and linings for standard size doors. The door frames are cut from sections of 102×64 mm and 89×64 mm rebated for doors and with sills for external doors. Door linings (or casings as they are sometimes called) are cut from sections 138×38, 138×32, 115×38 mm and 115×32 mm rebated for doors. The width of these linings, which is chosen to suit common partition and plaster thicknesses, may not match the overall thickness of some partitions and finishes.

Door sets

Door sets (door assemblies) are combinations of doors with door frames or linings and hardware such as hinges and furniture, prepared as a package ready for use on site. This plainly makes economic sense where many similar doors are to be used and packets of doors can be ordered and delivered instead of separately ordering doors, frames and hardware.

There is often inadequate fixing for a door frame or lining in a thin non-loadbearing partition so that the door, in use, may cause some movement in the frame or lining relative to the partition, to the extent that cracks in finishes around the frame or lining and particularly in the partition over the head of the door may appear. To provide a more secure fixing for doors in thin partitions it is often practice to use storey-height frames that can be fixed at floor and ceiling level.
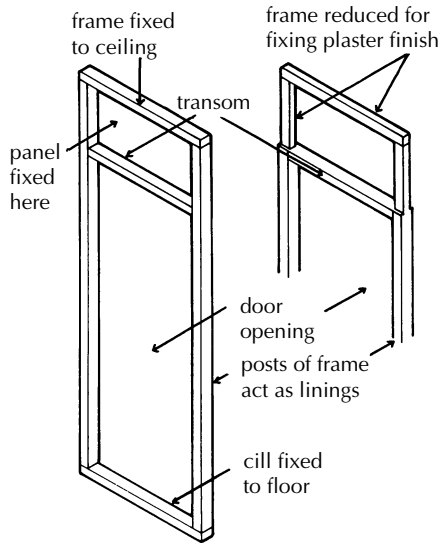
Figure 8.45   Storey height door frame.

These storey-height or floor-height frames are cut to line the reveal of the door opening and in that sense serve as linings, and are put together with floor-height posts, a head that can be fixed to the ceiling, a transom at the head of the door and also a cill for fixing to the floor, as illustrated in Figure 8.45. The frame sections may be rebated for the door or be plain with planted stops. The frame may be of uniform width for the full height with a panel fixed in the space over the door, or the width of the frame may be reduced over the door so that finishes, such as plaster, may be run across the frame over the door. The cill of the storey-height door frame may be fixed to the floor so that floor boards can be fixed over it or finished flush with the floor finish for carpeted finishes. The advantage of these frames is that they provide a degree of stability to block, non-loadbearing partitions.

Metal door frames

Metal door frames are manufactured from mild steel strip pressed into one of three standard profiles. The same profile is used for head and jambs of the frame. The three pressed steel members are welded together at angles. After manufacture the frames are hot-dip galvanised to protect the steel against corrosion. Two loose pin butt hinges are welded to one jamb of the frame and an adjustable, lock strike plate to the other. Two rubber buffers are fitted into the rebate of the jambs to which the door closes to cushion the impact of sound of the door closing. Figure 8.46 is an illustration of a standard metal door frame. The frames are made to suit standard door sizes. The frames are provided with

**Adjustable building in lug for
metal door frames**
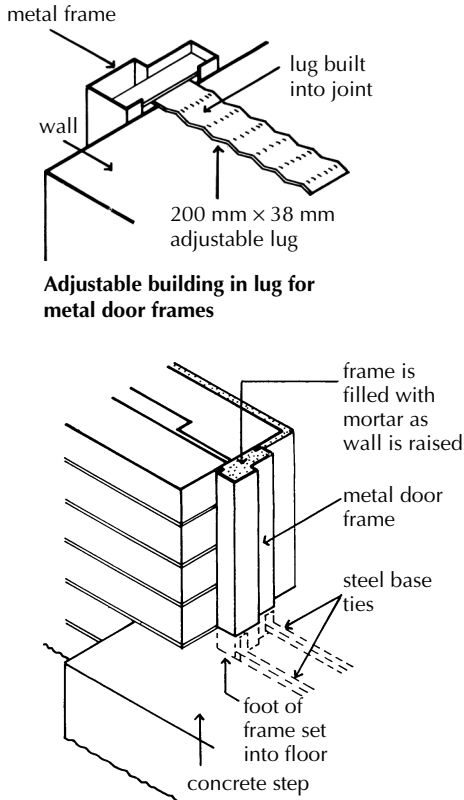
Figure 8.46   Metal door frame.

steel, base ties welded across the foot of the posts of the frame to maintain the correct spacing of the posts.

Metal door frames are built-in and secured with adjustable, metal building-in lugs that are bedded in the horizontal joints of brick or blockwork, three to each side (Figure 8.46). The frames are bedded in mortar and filled with mortar. Alternatively, frames can be fitted-in, after the brickwork has been raised. When the frame is fitted in the fixing lugs are fitted to the internal leaf of the cavity wall.

These frames are made to suit standard external and internal wood doors. When used for internal doors in non-loadbearing partitions a profile of metal frame is selected that is wider than the combined thickness of the partition and plaster both sides. In this way the metal frame serves as a door lining that projects some 16 mm each side of the finished plaster. Plaster is run up to and under the lipped edges of the frame to avoid the necessity for an architrave to mask the junction between plaster and frame.

door lipped
top & sides

steel frame
wood insert

sheet steel panels
welded around
core

honeycomb core
40 mm thick
wood insert
floor

wood insert

flush
steel door

hinge

rubber stop

jamb of
frame
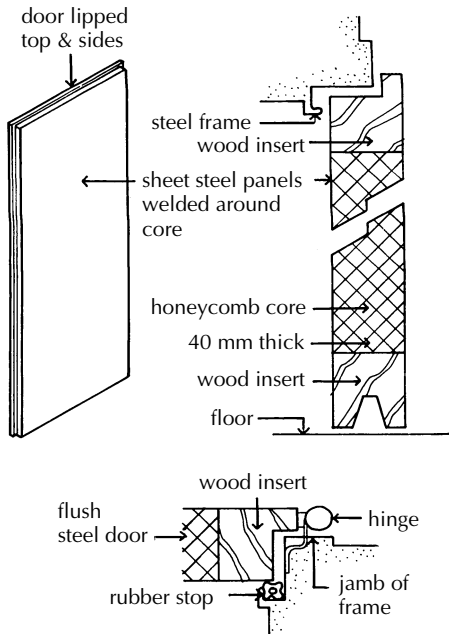
Figure 8.47   Flush steel door.

Glazed steel doors

Glazed steel doors are fabricated from the hot rolled steel sections used for windows. The sections are assembled with welded corner joints. The doors and frames, which are hot dip galvanised after manufacture, may be finished with an organic powder coating. Single glass is either putty or clip-on aluminium bead glazed. Double glazing is bedded in mastic tape and secured with clip-on aluminium beads. Glazed steel doors, which have largely been superseded by aluminium doors, are mainly used for replacement work.

Flush steel doors (Figure 8.47) are manufactured from sheet steel, which is pressed to shape, often with lipped edges, hot dip galvanised and either seam welded or joined with plastic, thermal break seals around a fibre board, chip board or foamed insulation core, generally with edge, wood inserts as framing and to facilitate the fixing of hardware. The sheet steel facings may be flush faced or pressed to imitate wood panelling or with glazed panels. The exposed faces of the doors may be finished ready for painting or with a stoved on organic powder or liquid coating.

Aluminium doors

An extensive range of partly-glazed and fully-glazed doors is manufactured from extruded aluminium sections. The slender sections possible with the

material in framing the doors provide the maximum area of glass. These glazed doors, commonly advertised as 'patio doors', are made as both single-and multi-leaf doors to hinge, slide or slide and fold to open. Glazed doors serve as a window by virtue of the large area of glass, and as doors by the facility to open them from floor level. The particular use of these doors is to provide a large area of clear glass for an unobstructed view out to gardens and to give ready access from inside to outside. To minimise condensation on the inside faces of these double glazed doors it is practice to fabricate them as thermal break doors. The main framing sections of the doors, which are joined with corner cleats, are fixed to aluminium facings through plastic sections that act as a thermal break. Figure 8.48 is an illustration of an aluminium section glazed door designed to slide open. The doors are double glazed to reduce heat loss and have weatherstripping and drainage channels to exclude wind and rain.
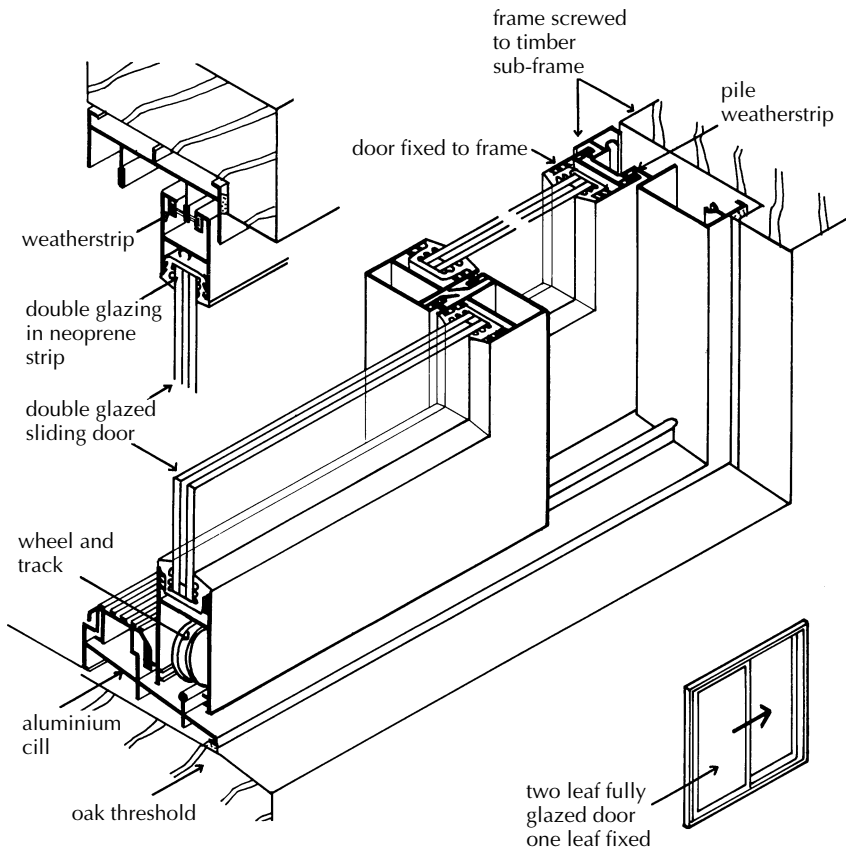
Figure 8.48   Fully glazed aluminium horizontally sliding door.

Of recent years single-leaf aluminium doors have been made to resemble traditional panelled wood doors. These are framed from extruded aluminium sections in the same way that windows and fully glazed doors are fabricated with the addition of a middle, horizontal rail to imitate the middle or lock rail of a wood door. The sections are made to take either glazed or solid panels secured with internal pop-in glazing beads. The solid panels, which are fabricated from PVC or glass fibre reinforced plastic sheets around an insulating core, may be moulded to imitate traditional wood panels. An advantage is that they may be finished in a range of coloured powder or liquid coatings that do not require periodic painting for maintenance. These doors are sufficiently robust for use in domestic buildings and may be fabricated as thermal break construction to minimise condensation on the internal faces of the aluminium framing.

uPVC doors

Single leaf uPVC doors are fabricated from a frame of comparatively bulky, extruded uPVC hollow sections similar in size to the stiles and rails of wood framed doors. The hollow framing sections are reinforced with galvanised steel or aluminium sections in the main cell of the hollow sections that are mitred and heat fusion welded at corners. A mid rail member is fitted to match the middle or lock rail of a wood door. These door leafs are hung to extruded, hollow section uPVC frames and thresholds as illustrated in Figure 8.49.

The uPVC door leafs, which are framed for glazing with single or double glazing secured with internal pop-in beads, are weathered with wedge and blade gaskets. As an alternative to glazed panels a variety of plastic panels are produced from press moulded acrylic, generally moulded to imitate wood door panels either as full door height panels or as two panels fitted to a middle rail.

The hollow panels may have a core of some insulating material and a foil or thin sheet of aluminium as a barrier to breaking and entering by fracturing the panel. The majority of these doors are made as white or off-white impact modified uPVC to minimise the considerable thermal expansion that this material suffers as a result of solar radiation. Coloured and wood grain finishes are also supplied.

The advantage of uPVC doors is that they require no maintenance during their useful life, other than occasional washing. The disadvantage of these doors is that they may suffer thermal expansion causing them to jam, and knocks and indentations cannot be disguised by painting.

Garage doors

Up and over garage doors

Pressed metal doors are suited for use as garage doors because they are lightweight and have adequate stiffness and shape stability for a balanced 'up-and-over' opening action. The doors are manufactured from pressed steel
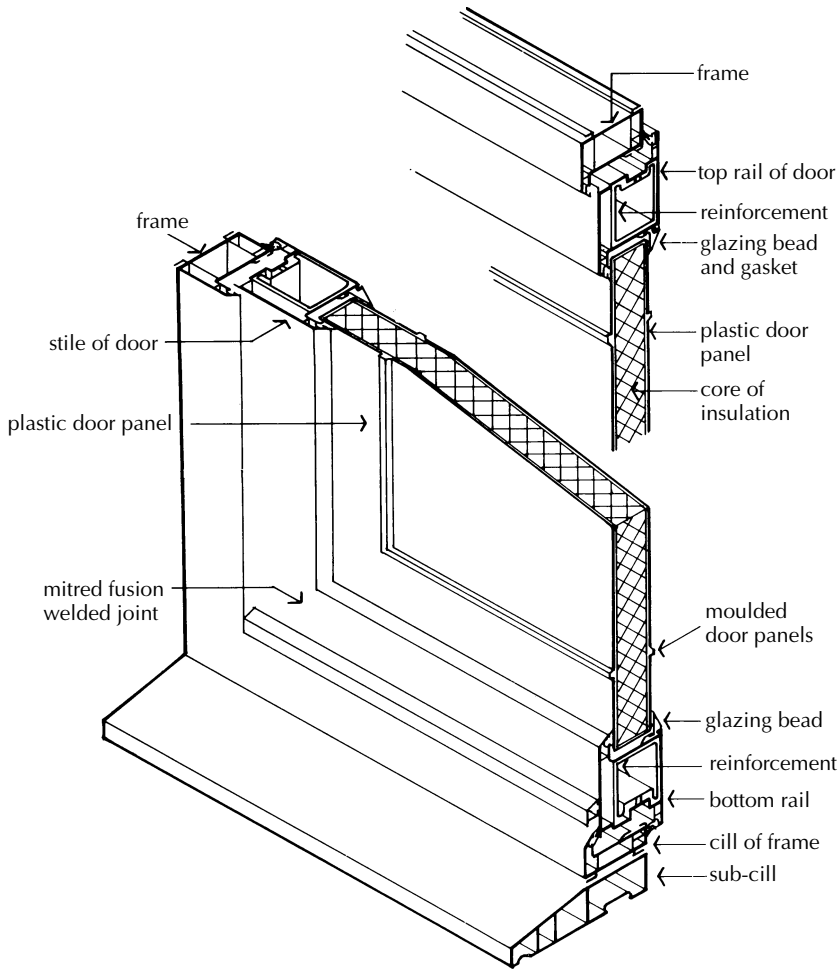
Figure 8.49   uPVC door and frame.

or aluminium sheet, which is profiled to give the thin sheet material some stiffness. The sheet is welded or screwed to a light frame to give the door sufficient rigidity. Steel doors are hot-dip galvanised and primed for painting or coated with PVC, and aluminium doors are anodised. Figure 8.50 is an illustration of a steel up-and-over garage door.

To open, the door is lifted to slide on wheels in overhead tracks under the roof of the garage. Spring loaded side stays attached by pivots to the base of the door serve to steady the upward and downward movement of the door leaf and serve to balance the movement so that it may easily be raised and lowered by hand. The advantage of the overhead action is that the door does not obtrude on the outside.
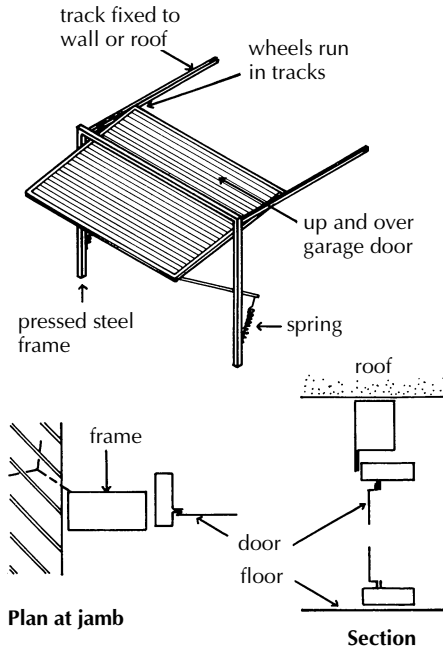
Figure 8.50   Steel 'up-and-over' garage door.

Electronic opening devices may be fitted to garage doors that eliminate the need to lift the doors by hand. A sensor placed in the car will trigger the door opening when approaching the garage door. A wide range of electronic opening devices and associated doors are available.

8.4 Hardware

Hardware is the general term used for the hinges, locks, bolts, latches and handles for a door. Ironmongery was a term used when most of these were made of iron or steel. The term 'door furniture' is sometimes used to describe locks, handles and levers for doors.

Hinges

Pressed steel butt hinge
Pressed steel butt hinges are the cheapest and most commonly used hinges. They are made from steel strip, which is cut and pressed around a pin, as illustrated in Figure 8.51. They are used for hanging doors, casements and ventlights. The pin of the standard butt hinge is fixed inside the knuckle. These hinges are also made as loose pin butt hinges, with the flap, which is screwed
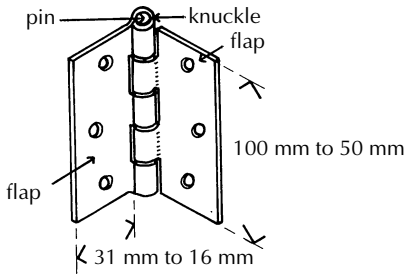
Figure 8.51   Pressed steel butt hinges.

to the edge of the door, loose inside the knuckle so that the doors can be taken off by lifting. This avoids the necessity of unscrewing one flap of each hinge to take the door off for adjustment and for repair. These hinges are usually galvanised as protection against corrosion. The two flaps of the hinge are screwed in position into shallow sinkings cut in the wood frame and edge of the door respectively so that they are flush with the wood faces and with the knuckle of the hinge protruding from the face of the door.

Double pressed steel butt hinge
Double pressed, heavy, steel butt hinges are made of two strips of steel each folded back on itself as a flap and pressed and cut to form the knuckle around the pin as illustrated in Figure 8.52. Because of the double thickness of steel strip from which they are made, these hinges serve as heavy duty to support larger, thicker doors.

Rising butt hinge
The bearing surfaces of the knuckle of both flaps of the rising butt hinge are cut on the skew so that as the hinge opens one flap rises, as illustrated in
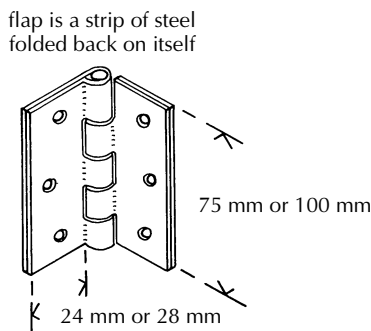
Figure 8.52   Double pressed heavy steel butt hinge.
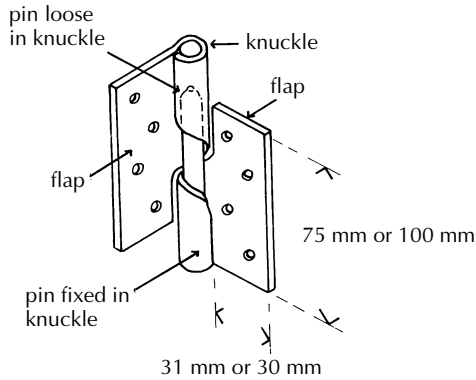
Figure 8.53   Steel skew butt hinge (rising butt hinge).

Figure 8.53. Because of the action of the hinge, as it opens, these hinges are generally described as 'rising butt hinges'. These hinges are used for hanging doors so that as the door opens it rises over and so clears such floor coverings as fitted carpets to reduce wear. The action of the skew butt will tend to make all but the lightest doors, self-closing.

Tee hinge
Steel tee hinges, illustrated in Figure 8.54, comprise a rectangular steel flap and a long tail, or hinge, which are pressed around a pin as knuckles. These hinges are made for use with matchboarded doors where the length of the long tail of the hinge will give support across the face of the door rather than at the edge. They are pressed from mild steel strip and either galvanised or painted ready for fixing.

Hook and band
This hinge, illustrated in Figure 8.55, is fixed in a housing in the wood door frame and to the face of the door. Hook and band hinges are made of more
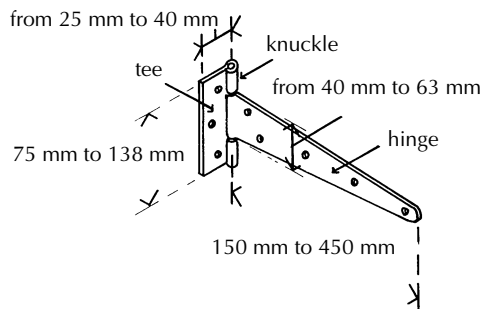
Figure 8.54   Steel tee hinge.
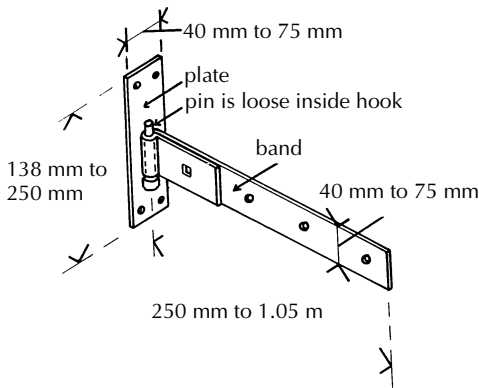
Figure 8.55 Hook and band hinge.

substantial thicknesses of steel than tee hinges to support heavy wood doors, such as those to garages and workshops. The plate has a pin welded to it, around which the knuckle of the band fits as illustrated in Figure 8.55. The band is reinforced with a second plate of steel at the knuckle end. As protection against rusting the hinge is galvanised after manufacture.

To provide secure support for the doors the band is holed towards its knuckle end for a coach bolt that is fitted to a hole in the stile of the door and bolted in place to provide solid support. For convenience in taking doors off for easing (trimming to fit) the hinge fits to a loose pin on the plate.

Latches and locks

The word latch is used to describe any wood or metal device that is attached to a door or window to keep it closed. These simple devices serve the purpose of keeping the door or window in the closed position. They do not lock the door.

A lock is any device of wood or metal which is attached to a door or window to keep it closed by the operation of a bolt that moves horizontally into a striking plate or staple fixed to the door or window frame.

Mortice lock

The mechanism most used today for doors is the mortice lock, so called because the metal case containing the operating parts is set into a mortice cut in the door. Locks for external doors and internal doors, where security is a consideration, consist of a latch bolt and a lock bolt. For internal doors in continuous use the locks contain a single latch bolt to keep the door closed.

A mortice lock for an external door is set inside a mortice cut in the stile and middle rail of the door. The horizontal, two bolt mortice lock, illustrated in Figure 8.56, consists of a case, a forend and a striking plate. The case fits into
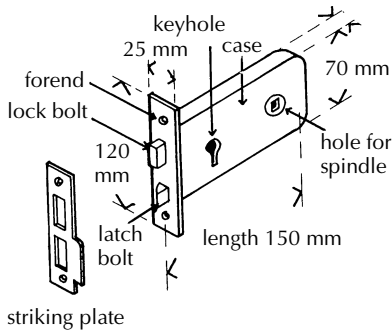
Figure 8.56   Horizontal two bolt mortice lock.

a mortice in the door through which holes have been drilled for a loose key and for the spindle for knobs or handles. The lock may be made with a forend plate that is screwed into position flush with the edge of the door or finished with a forend and cover plate of brass for appearance sake.

A striking plate is fixed over mortices cut in the door frame to house the two bolts. This plate is termed a striking plate, as it serves the purpose of directing the shaped end of the latch bolt into the plate as the door is shut.

For flush doors and those without a middle rail, an upright two bolt mortice lock is used. The lock, illustrated in Figure 8.57, is designed specifically for this use. Two bolt mortice locks are supplied with two loose keys to operate the lock bolt.

Single bolt mortice locks, which are supplied for internal doors comprise a case, forend and striking plate with one latch bolt which is operated by knobs or lever handles and a spindle. As they do not lock the door, these devices should properly be called latches. Light duty internal doors, which are often too thin to accommodate a mortice lock may be secured with a rim lock. These locks are designed for fixing to the face of doors (Figure 8.58).
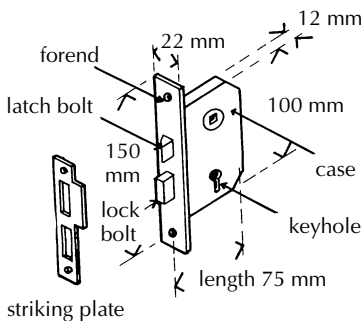
Figure 8.57   Upright two bolt mortice lock.
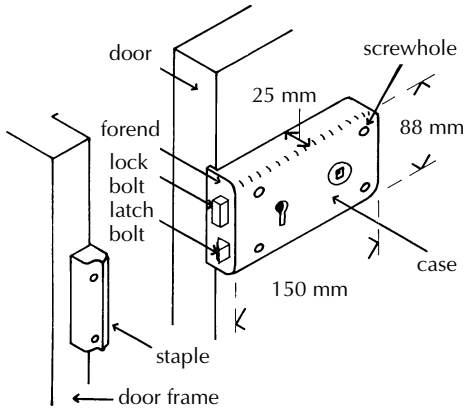
Figure 8.58   Horizontal two bolt rim lock.

Mortice dead lock

A mortice dead lock consists of a single bolt that is operated by a loose key. There is no latch bolt. It is a dead lock in the sense that once the bolt is shot, moved into the closed position, and the key removed it is dead to being operated. These locks are used in conjunction with and separate from a cylinder night latch for security. The upright case is housed in a mortice cut in the stile of the door and screwed through the forend to the edge of the door. The lock bolt is closed into a lock plate screwed over a mortice cut into the door frame. Figure 8.59 is an illustration of a typical dead lock.

The security of this locking device depends to an extent on the number of so called levers that are operated by the key. The greater the number of levers, the greater the security. This type of lock may be used for both wood doors and wood casement windows where the stile of the casement is wide enough to house the lock case.
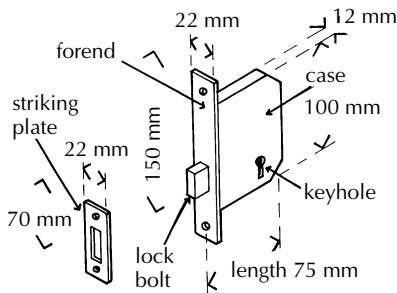
Figure 8.59   Mortice dead lock.
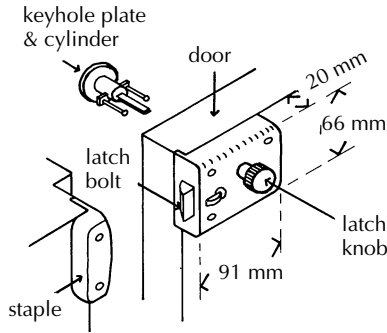
Figure 8.60   Cylinder rim night latch.

Cylinder rim night latch (springlatch)

A cylinder night latch is designed to act as a latch from inside and a lock from outside for convenience in use on front doors. It is made as a rim latch for fixing to the inside face of doors (Figure 8.60). This type of latch offers poor security as it is fairly easy to push back the latch from outside by means of a piece of thin plastic or metal inserted between the door and frame.

A more secure type of night latch is designed as a mortice lock which is opened as a latch from inside by means of a lever and from outside by a loose key. The lock has a double throw action which, by two turns of the key from outside, locks the latch in position so that it cannot be pushed back from outside. As it is the most convenient means of keeping external front doors closed by use of a latch bolt and offers some small security through its operation of opening from outside by a loose key, this lock is much favoured. It should be used in conjunction with a mortice lock to entrance doors to houses and flats.
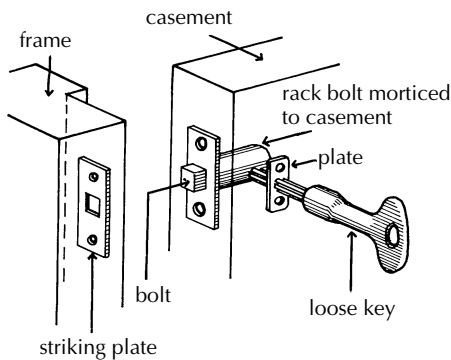
Figure 8.61   Rack bolt for security for wood windows and doors.

Rack bolt

A rack bolt is a single locking device used for locking wood doors and casement windows. It consists of a cylindrical case and bolt that is fitted into a mortice cut in the stile of doors and casements of windows as illustrated in Figure 8.61. A loose key from inside the door or window operates the bolt.

The bolt is fitted to a mortice in the door or window and the forend screwed to a shallow housing in the door or window edge. A striking plate is fixed over a mortice in the frame and screwed in position in a shallow housing. Two of these rack bolts fitted top and bottom to doors and casements or one to small casements serve as an economical and very effective means of locking shut.

Entry control systems

Flats and residential developments, such as sheltered housing, need to provide entry to communal and private space. This has to be done without compromising the security of the residents. Entry control systems that incorporate closed circuit television monitoring allow remote operation by individual tenants and are widely used.

9   Stairs and Ramps

For access between floors and different levels in buildings a ladder, stair or ramp is used. Lifts and escalators are also used for vertical circulation and are covered in *Barry's Advanced Construction of Buildings*. Accessibility for all, regardless of disability, must be addressed when considering changes in level, no matter how small the difference in the height of finished floor surfaces.

Definitions

Ladders

A ladder is made as a series of narrow horizontal steps (rungs), fixed between two uprights of wood or metal, on which a person usually ascends (climbs up) or descends (climbs down) facing the ladder. A ladder may be fixed in an upright, vertical position or more usually at a slight angle to the vertical for ease of use (Figure 9.1A). Approved Document K recommends that a ladder should only be used for access to a loft conversion of one room, where there is not enough space for a stair, and that the ladder be fixed in position and fitted with handrails both sides.

Stairs

A stair, or stairway, is the name given to a set of steps formed or constructed to make it possible to pass to another level on foot by putting one foot after the other on alternate steps to climb up or down the stair. A stair may be formed as a series of steps rising in one direction between floors as a straight flight of steps. More usually a stair is formed as two or more straight flights of steps arranged to make a quarter or half turn at intermediate landings between floors. Using two flights helps to limit the number of steps in each flight making use of the stairway potentially safer. Because of the slope of the stair and the need to limit the number of steps in each flight a typical half turn stair occupies a considerable space in small houses as illustrated in Figure 9.1B.

A stair is the conventional means of vertical access between floors in buildings. It should be constructed to provide ready, easy, comfortable and safe access up and down with steps that are easy to climb, within a compact area, so as not to take up excessive floor space. Access for wheelchair users and less mobile persons may be facilitated by the inclusion of chairlifts fixed to the side

A   Ladder

B   Half turn stair
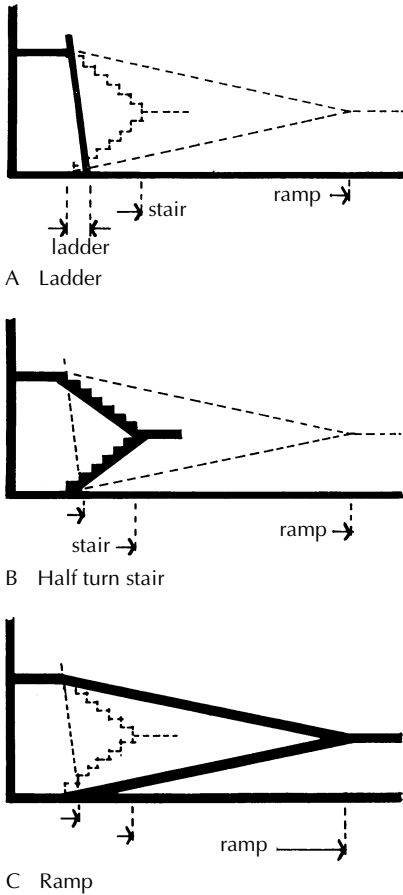
C   Ramp

Figure 9.1   Space used by: (A) ladder, (B) half turn stair, and (C) ramp.

of the staircase. In such cases adequate attention needs to be given to the stair width and overall design and installation of the stair and associated fittings (Figure 9.2).

Ramps

A ramp is a surface, sloping uniformly as an inclined plane, linking different levels. A ramp is formed or constructed at a slope of at least 1 in 20 (1 m rise vertically in 20 m horizontally). Because of the comparatively shallow slope of a ramp it occupies a considerable area and this must be considered early in the design process so that enough room is allowed (Figure 9.1C). The advantage of a ramp is that it allows relatively easy and safe access for wheelchairs and pushchairs and may be less daunting than a staircase to people with mobility difficulties.
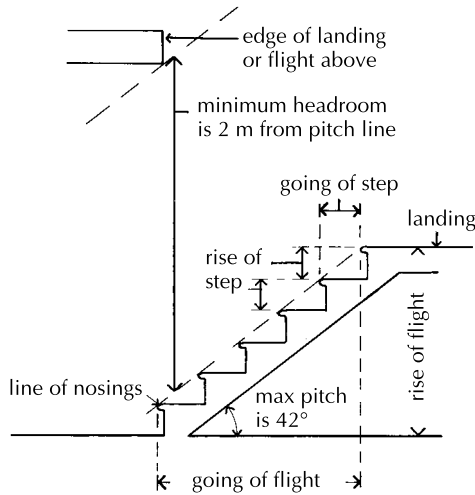
Figure 9.2   Rise, going and headroom for stairs.

9.1 Functional requirements

The primary functional requirement of a stair or ramp is

❑ To allow vertical movement, safely, from one level to another

Additional functions and performance requirements include:

❑ Strength and stability – must support people, fixtures and fitting (imposed and dead loads)
❑ Ease of use and aid movement – provide handrails and landings suitable for users (including disabled use); ensure gradient suitable for users
❑ Fire safety – remain stable in fire and resist spread of fire
❑ Control of impact sound – reduce passage of impact sound
❑ Safety in use – reduced risk of slips, trips and falling
❑ Avoid risk of trapping – handrail suitably positioned to prevent fingers being trapped, open stairs and balustrade gaps restricted to prevent a child's head becoming lodged
❑ Durability
❑ Aesthetics

Strength and stability
A stair, or ramp, and its associated landings serves much the same function as a floor in the support of the occupants of a building, with the stepped

inclined plane of flights, or shallow rise of the ramp, serving as support for movement between different levels. The requirements for strength and stability in supporting dead and imposed loads for floors apply equally to stairs and ramps.

Ease of use

Many different people will use the stairway. Care should be taken so that stairs are designed for the able and less able. Consideration should be given to young users, old users and disabled. Handrails can help all users, but are particularly important for those less able to move between levels. Landings may provide well needed resting stages, or a platform that allows able users to pass, enabling the slower users to move at their own pace.

Fire safety

Stairs are one of the principal means of escape to the outside in case of fires in buildings. Stairs should be constructed of materials that are capable of maintaining strength and stability for a period of time sufficient for those in a building to escape to the outside or a protected area. Careful choice of materials is important, but so too is the protection of the stairs or ramp (the means of escape) from fire and smoke. The size of the steps and the width of the stair should be adequate for the safe escape of those in the building.

Whenever a stairway forms part of an escape route, considerable attention should be given to the requirements imposed in Approved Document B Fire Safety. Stairways that form part of an escape route will need to be of sufficient width to allow the occupants to evacuate the building safely. Table 9.1 provides widths for vertical escape routes (protected stairways).

Table 9.1   Widths of vertical escape routes and exits (adapted from Approved Document B DETR, 2000).

Widths of vertical escape route and exits		
Situation of stair (or ramp)	Max. no. of people served	Minimum width (mm)
In an institutional building (unless only used by staff)	150	1000
In an assembly building and serving an area used for assembly purposes (unless less than 100 m^3)	220	1100
In any other building and serving an area with an occupancy of more than 50	over 220	*
Firefighting stair		1100
Any stair not described above	50	800

*Table 7 and 8 of Approved Document B provide widths for stairs used in simultaneous evacuation (stairs must allow all people to leave the building at once) and phased evacuation (parts of the building may be evacuated before others).

Where a stairway provides access to more than one dwelling it should be situated in a fire resisting enclosure (protected shaft). Protected stairways need to be relatively free of potential sources of fire and all escape routes should have adequate artificial lighting. Escape lighting that automatically illuminates if the main electrical supply fails should also be provided.

Impact sound

Consideration of materials used for the stair tread is an important factor in helping to keep impact sound from foot traffic to an acceptable minimum. For example, metal treads and timber treads can be noisy and may be a nuisance to building users. This may not be a problem in a busy bar, but in a house the impact sound could prove a significant irritation to the building users. Direct impact sound can be reduced by using resilient packing between stairways and the building structure and/or with the use of dense material that absorbs sound energy, such as concrete.

Safety in use

A considerable number of accidents occur on stairs each year. While many of these are due to simple trips and falls, many are a result of damaged, broken or incorrectly fitted treads and handrails. It is essential that both the handrail and flight of stairs are securely fixed at the right height; an observation that also applies to the design of ramps. The guidance in Approved Document K is concerned with the safety of users in determining the rise, going and headroom of stairs and the dimensions of handrails and guarding. Guidance on ramps also covers the incline of the ramp and its uninterrupted length, positioning of landings, handrails and guarding.

Avoiding traps

Gaps in stairs can pose a problem to all users. Poorly positioned handrails, where the gap between the wall and the handrail is small or the space narrows such that fingers become trapped can result in bruised, broken and even amputated fingers. Care should be taken to avoid gaps where a child's head may become stuck. Fixing brackets and variations in the walls can cause the gap to become a hazard. Sharp or protruding objects, such as exposed wood grain, screws and bolts can easily cut and injure hands as they move across the handrail.

Durability

The durability of a stair or ramp will be determined by the type of building it serves, the amount of use received in service, and whether it is located within or outside the building envelope. Both internal and external stairs and

ramps will need to remain functional and safe despite heavy use, therefore the material used and any applied finishes must be relatively durable. Materials that wear easily and become loose or unstable are not suitable for stairways and ramps.

Aesthetics

In addition to their functional requirements, the stair or ramp may be designed to be a significant architectural feature within a building. Aesthetic requirements will determine the position and shape of the stairs or ramp as well as the materials used to construct it. Architectural fashion and increased attention to interior design has led to a big increase in the designs and materials used in stairs and ramps. In particular, stainless steel and structural glass have become very popular, with stairs and ramps forming an integral part of the building's character.

9.2 Materials, terms and definitiions

Internal stairs and ramps must be durable to everyday use while external stairs and ramps must withstand weathering and be durable to everyday use. Timber, stone, concrete, metal, stainless steel and, more recently, structural glass are the main materials used in the construction of stairs and ramps (see below). Factory made pre-fabricated staircases are now used in the majority of developments. Timber stairs are the most common, but steel and glass stairs are also manufactured off-site and delivered as discrete components.

Terms and definitions

There are a number of terms and definitions that are used to describe discrete elements of stairs and ramps. These are explained below.

Flight

The word flight describes an uninterrupted series of steps between floors or between floor and landing, or between landing and landing. A flight should have no more than 16 risers. Single steps should be avoided because they are a hazard. Small changes in height are not always obvious. Where single steps exist it will be necessary to provide visual warnings, e.g. contrasting colours should be used on the tread and rise, to warn people of the level change.

The rise and going of each step in one flight and in flights and landings between floors should be equal. Variations in the rise of steps will interrupt the rhythm of going up or down. Where levels are different people using the stair may trip or miss the step.

A   Stairway: glass cladding exposes stairway to the public

B   Glass balustrades provide a feature, expose movement of people and reduce the risk of children climbing

C   Open stairways with glass handrails, behind glass cladding combine internal and external features to enhance views from inside and outside the building
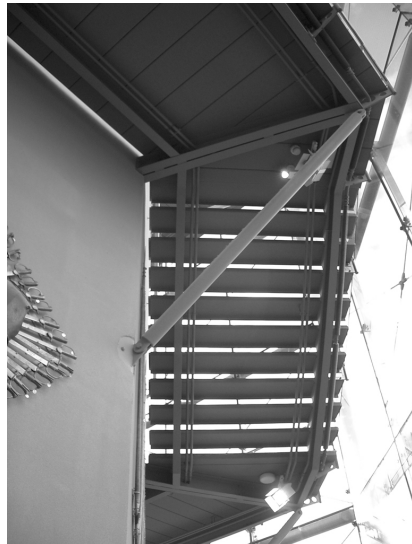
D   The heavy cantilevered supporting steel structure has a visual impact. Open stair allows external light to penetrate gaps

Photograph 9.1   Stairway design and aesthetics.

The *tread* is the full length
of the horizontal platform.

Tread

The *going* is the
horizontal distance
between the front of
the nosing on one
tread and the front of
the nosing on the
next tread

Going

Rise

The *rise* is the
vertical distance
between the top
surface of one
tread and the top
surface of the next

The riser

Nosing
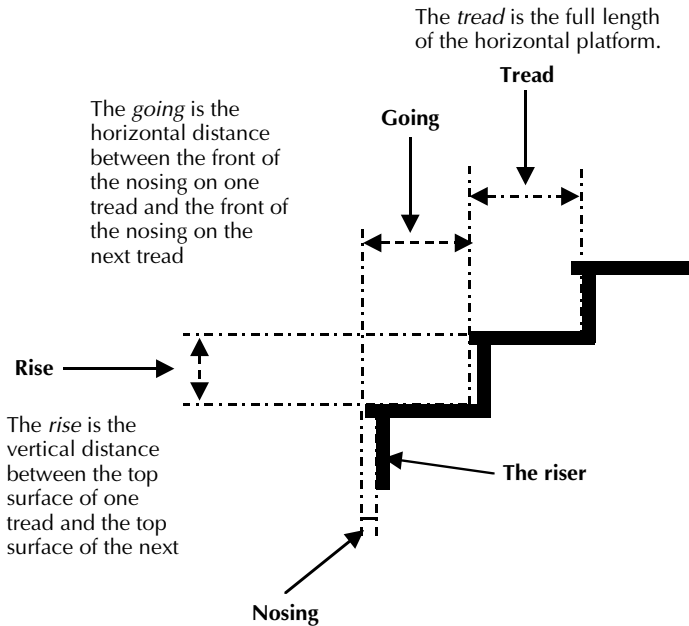
Figure 9.3   Stair terminology.

Approved Document K (Protection from falling) of the Building Regulations
does not provide a specified flight width; however, if the stair is to form part of
an escape route Approved Document B (Fire Safety) will apply (see Table 9.1
above) or, if designed for use by disabled people, Approved Document M
(access for disabled people) applies.

Treads and risers

The steps of a stair may be constructed as a series of horizontal open treads
with a space between the treads or as enclosed steps with a vertical face
between the treads, called a riser. The horizontal surface of a step is de-
scribed as the tread and the vertical or near vertical face as the riser. Reference
should be made to Approved Document to Part M for stair dimensions for
access for disabled people. With enclosed steps the treads usually project be-
yond the face of the riser as a nosing to provide as wide a surface of tread
as practicable. Figure 9.3 illustrates the use of the terms tread, riser and
nosing.

A stair, which is constructed with horizontal treads with a space between
them, is described as an open riser stair (Figure 9.4). When open risers are
used and it is expected that children under the age of five years old will use the
stairs, the stair shall be constructed so that any openings in the flight would not
allow a 100 mm sphere to pass through it. Open treads should not be used when

Where the riser is open each
nosing must overlap the lower
step by a minimum of 16 mm

Downstand noses or
upstands at the back of
the tread can be used to
reduce the effective depth
of the gap

A sphere of 100 mm
diameter must not be
allowed to pass through
the gap between the stairs

Timber upstand at
the back of the
tread can be used
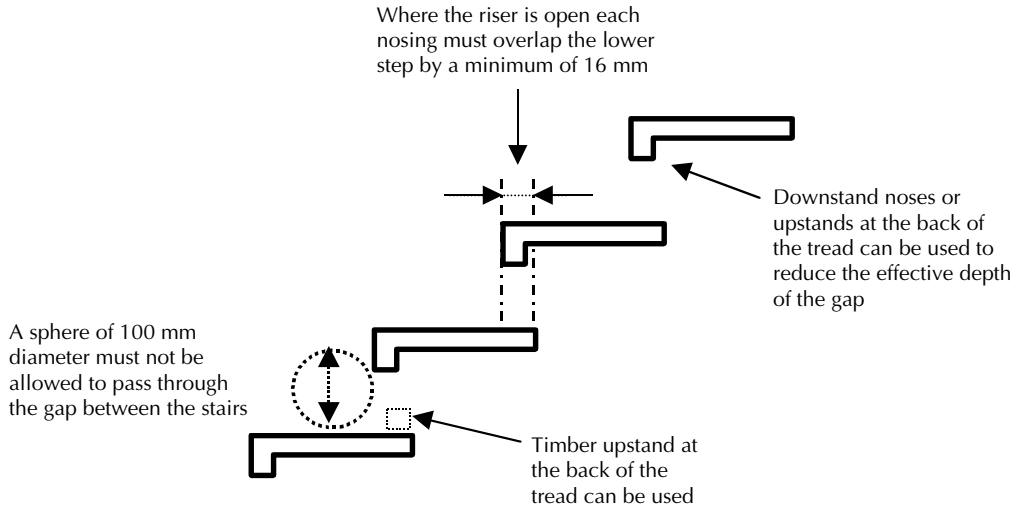
Figure 9.4   Open riser stairs.

stairs provide disabled access (Approved Document M). To help the visually impaired recognise and distinguish between steps, a 55 mm wide strip, which provides a visual contrast, should be permanently fixed to all nosings on both the tread and the riser.

The word rise describes the distance measured vertically from the surface of one tread to the surface of the next or the distance from the bottom to the top of

All treads should
be equal

The pitch line is formed by
striking a line across the
noses of all of the steps

All risers
should be
equal height

**Angle of
pitch**

FFL (Finish floor level)

Maximum pitch for
private domestic
construction is 42°
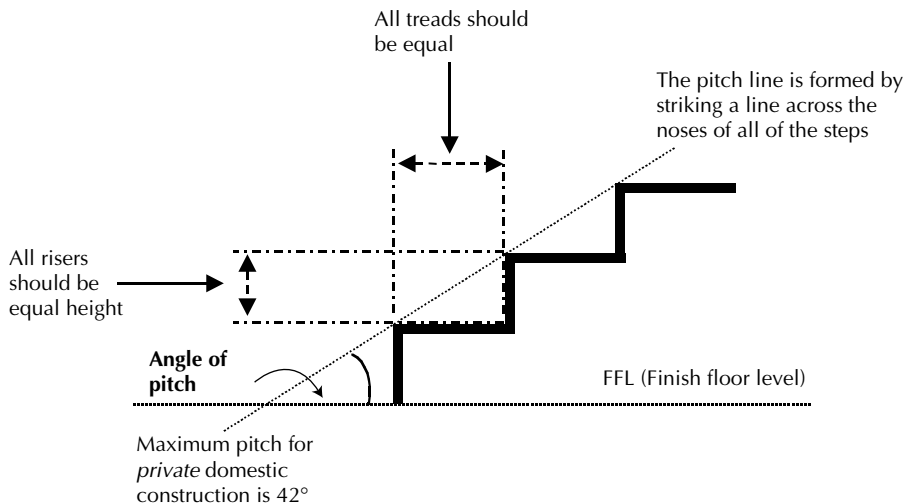
Figure 9.5   Angle of pitch.
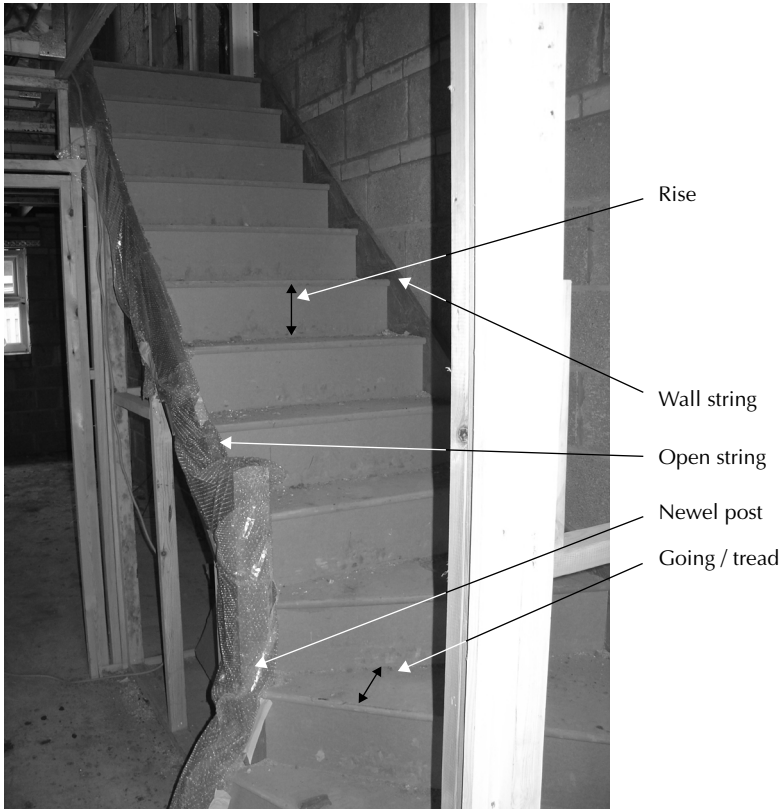
Photograph 9.2   Stair terminology.

a flight. The word going describes the distance, measured horizontally, from the face of the nosing of one riser to the face of the nosing of the next riser, as shown in Figure 9.3. The dimensions of the rise and going of steps determine whether a stair is steep or shallow.

The recommended rise and going for a private stairs in a dwelling is shown in Table 9.2 (from Approved Document K – Building Regulations).

The incline of a stair can be described either by the rise and going of the steps or as the pitch of the stair, which is the angle of inclination of the stair to the horizontal, as illustrated in Figure 9.5. Domestic stairs are pitched at not more than 42°.

Pitch

Before standards were set for the rise and going of steps it was practice to determine the pitch of a domestic stair from the simple formula: 'twice rise

Table 9.2   Maximum rise and minimum going of stairs.

Stairs – maximum rise and minimum going (mm)		
Stair classification	**Max. rise**	**Min. going**
Private (max pitch 42°) – Housing and domestic properties, intended to be used for one dwelling only	220	220
Institutional and assembly – Serving a place where a substantial number of people will gather	180[a]	280[b]
Stairs for use by disabled people (Approved Document M)	170	250
Stairs for use by disabled use in schools (Approved Document M)	170	280
Other – all other buildings	190[b]	250

[a] If the area of the floor of the building is less than 100 m^2, the going may be reduced to 250 mm.

[b] Maximum rise for stairs providing access for disabled people. Reference needs to be made to the Approved Document M of the Building Regulations.

plus going equals some notional figure, between 550 and 700 mm', where an assumption of some convenient rise was made.

To set out a stair it is necessary to select a suitable rise and adjust it, if necessary, to the height from floor to floor so that the rise of each step is the same, floor to floor, and then either select a suitable going or use the formula $2 Rises + 1 Going =$ between 550 and 700 mm, to determine the going.

Headroom

For people and for moving goods and furniture, a minimum headroom of 2 m, measured vertically, is recommended between the pitch line of the stair and the underside of the stairs, landings, and floors above the stair as illustrated in Figure 9.6.

Handrails

The general requirement for handrails is that there should be at least one handrail on a stairway. If the stairway is greater than 1 m, two handrails are required. The height of the handrails should be between 900 mm and 1 m. Where the stair acts as a gangway greater than 1.8 m wide, a handrail should be used to divide the stairway (Figures 9.7 and 9.8).

Approved Document M provides guidance on the size and height of handrails for use by disabled people. The handrail should be 900 to 1100 mm above the landing height and 900 mm to 1 m above the pitch line of the stair; the handrails should also start 300 mm before the first step and end at the top step (Figure 9.9).
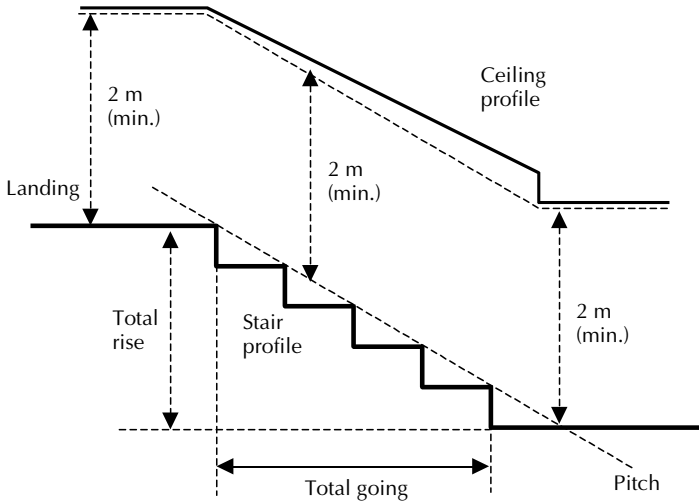
A   Minimum headroom
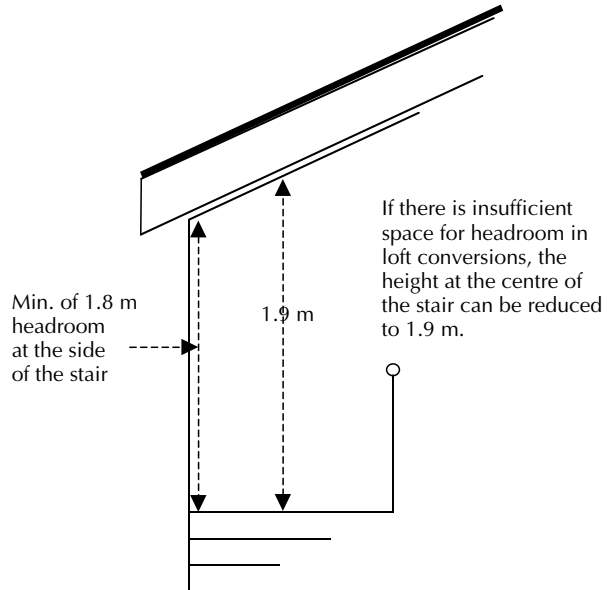
B   Minimum headroom in loft conversions

Figure 9.6   Minimum headroom.

Landings

The position and general arrangement of landings to stairs are illustrated in Figures 9.10–9.12. The maximum number of risers in any flight is 16 (12 for disabled use), after which a landing must be provided. The landing provides
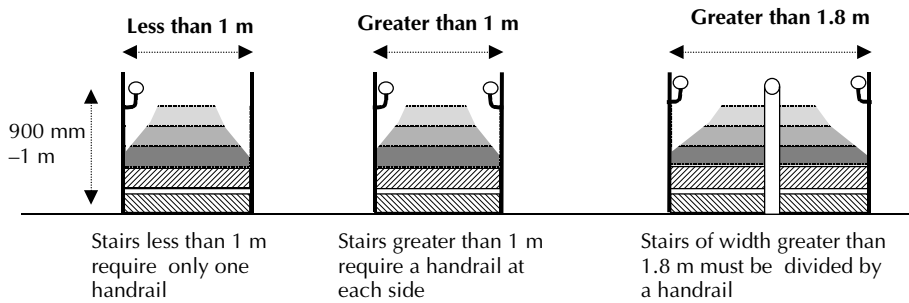
Figure 9.7   Handrails and stair widths.

a position for the stair user to rest, if necessary, before continuing up or down the stairs and thus is an important safety consideration. Landings should also be provided at changes of direction. When landings are designed for use by people with limited mobility they should have an unobstructed length of 1200 mm.
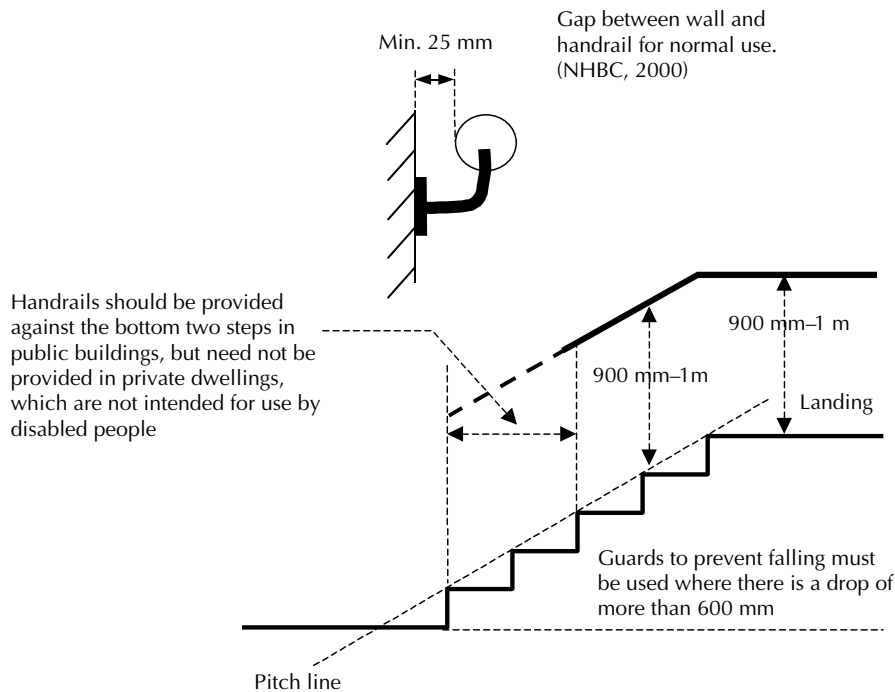
Figure 9.8   Handrail height for general use.

Circular handrails
40–45 mm diameter

Non circular handrails
50 mm wide (preferred width). Min. radius for ellipse 15 mm

50 mm

15 mm

Gap recommended between handrail and wall for disabled use (Approved Document M).

60–75 mm

50 mm

Mounted handrail

50 mm Max.

Requirements

Rise   = 150–170 mm
Going   = 250 mm (min.)
Landing = 1200 mm (min.)
55 mm visual contrast strip on rise and tread
Rise and going consistent
No open rises

300 mm

900–1100 mm

Level landing

900 mm–1 m

300 mm

900–1100 mm

Level landing

12 risers max. (16 risers in small premises where space is restricted)

Pitch line

Figure 9.9   Handrails for the disabled.

Stairs with more than 36 risers in consecutive flights should have a change in direction of at least 30°

Maximum 16 risers then a landing must be inserted

flight

landing   landing   landing

Angle at least 30°

flight   flight   flight
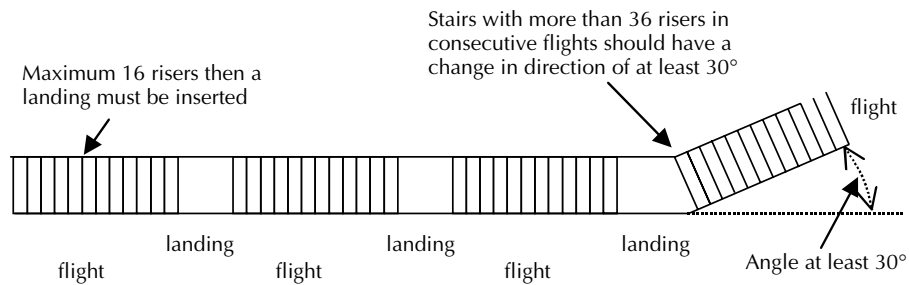
Figure 9.10   Change in direction.

Min. 400 mm

Maximum of 16 risers in a flight

Obstruction e.g. cupboard door

Max. 16

Min. 400 mm

Landing must have a clear unobstructed distance of at least 400 mm at the top and bottom of a flight of stairs
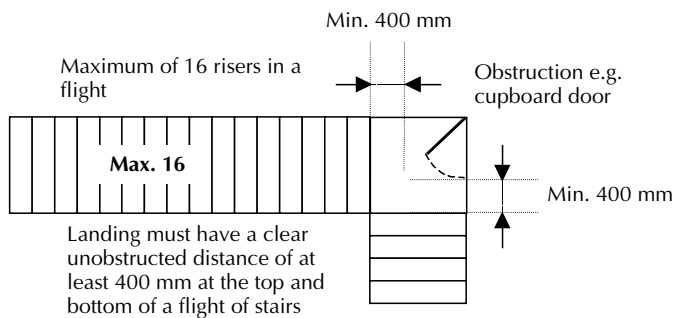
Figure 9.11   Maximum steps in flight – minimum unobstructed landing distance.

Min. width of stairs

Width of stairs

Length of the landing must be at least width of stairs
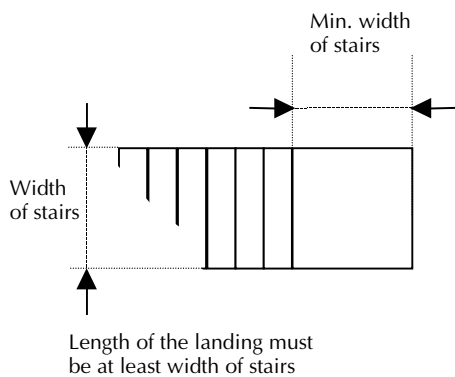
Figure 9.12   Length of landings.

9.3 Types of stair

The three basic ways in which stairs with parallel treads are planned are illustrated in Figure 9.13. These are a straight flight stair, a quarter turn stair, and a half turn stair.
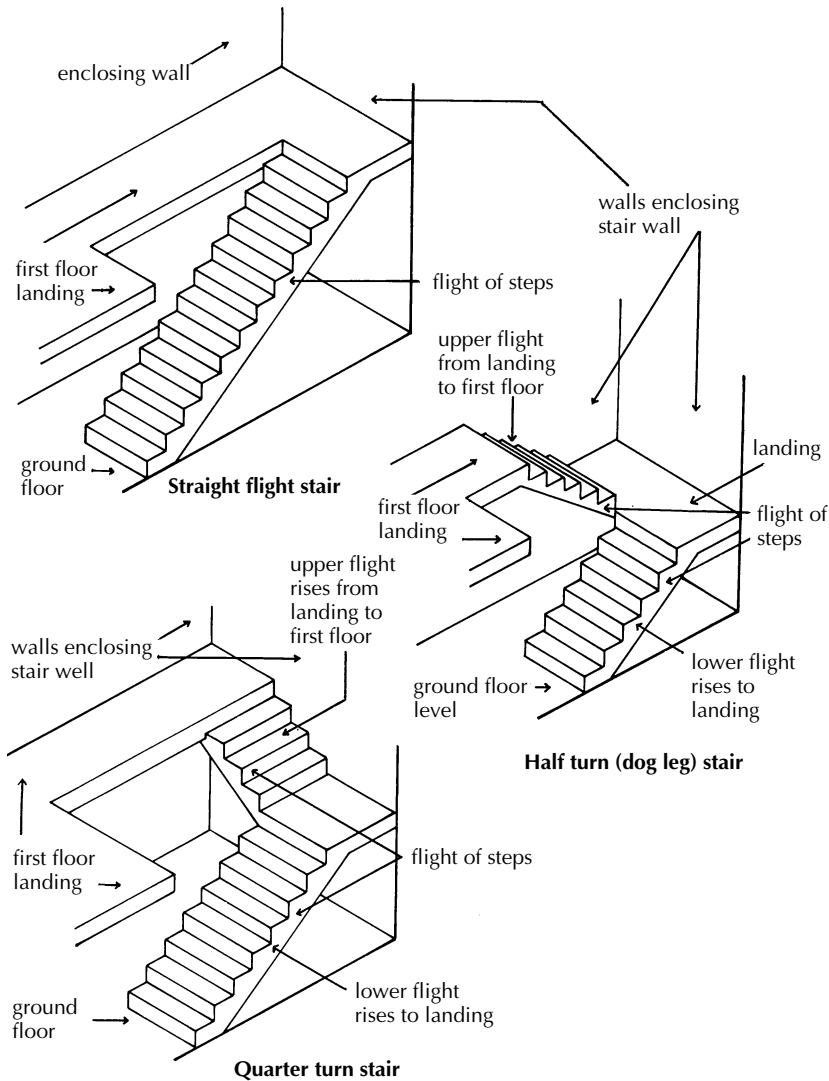
Figure 9.13   Stairs.

Stairs with parallel treads

Straight flight stair

A straight flight stair rises from floor to floor in one direction with or without an intermediate landing, hence the name straight flight. A straight flight stair was commonly used in the traditional 'two-up two-down' terraced house with the stair in the centre of the plan running from front to back giving access to the two upper rooms each side of the head of the stair, with access to the two ground floor rooms from the small hall at the foot of the stair. It is usually the most economical use of a stairs.

Quarter turn stair

A quarter turn stair rises to a landing between two floors, turns through 90°, and then rises to the floor above, hence 'quarter turn'. This type of staircase was much used in the two floor semi-detached houses built in the first half of the twentieth century, for its great economy in compact planning. The quarter space or quarter turn landing was often replaced with winders for further economy in the use of space.

Half turn or dog leg stair

A half turn stair rises to a landing between floors, turns through 180°, and then rises parallel to the lower flight to the floor above, hence 'half turn'. The landing is described as a half space or half turn landing. A half turn stair is often described as a 'dog leg' stair because it looks somewhat like the hind leg of a dog. This, the most common arrangement of stairs, has the advantage in planning that it lands at, or roughly over, the starting point of the stair which can be constructed within the confines of a vertical stair well, as a means of access to and escape from similar floors.

Stair well

Stairs are sometimes described as 'open well stairs'. The description refers to a space or well between flights. A half turn or dog leg stair can be arranged with no space between the flights or with a space or well between them and this arrangement is sometimes described as an open well stair. A quarter turn stair can also be arranged with a space or well between the flights. As the term 'open well' does not describe the arrangement of the flights of steps in a stair, it should only be used in conjunction with the more precise description straight flight, quarter or half turn stair (e.g. half turn stair with open well).

Geometrical stairs

Geometrical stairs are constructed with treads that are tapered on plan, with the tapered treads around a centre support as a spiral (helical) stair, an open

Spiral (helical) stair
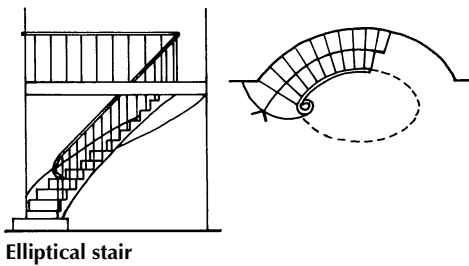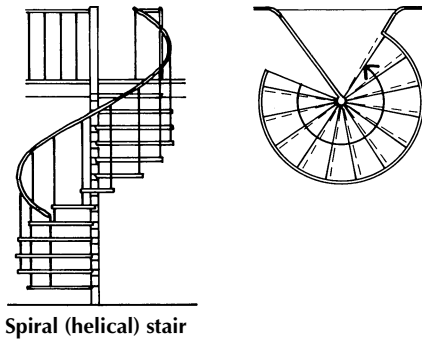
Elliptical stair

Figure 9.14   Geometrical stairs.

well circular stair or as an ellipse on part of an ellipse on plan, as illustrated in Figure 9.14.

A spiral (helical) stair with the treads tapering to a central, vertical support is the most economical way of planning a stair as it takes up little floor area. Because the treads taper sharply to the central post and one needs to make sharp turns up and down this type of stair, it is difficult to use and may be dangerous to young children and people with limited mobility. Spiral stairs, which form a helix around a central column or post, are used where space is limited for access to an intermediate floor of one room. A spiral stair is illustrated in Figure 9.14.

Circular or elliptical stairs are constructed around a generous open well with the treads having a shallow taper towards the well. These stairs, which are extravagant in the use of space, are used as a feature for grand means of access in large buildings. An elliptical stair is illustrated in Figure 9.14.

9.4 Timber staircases

A staircase, which is a stair with treads and risers constructed from timber boards put together in the same way as a box or case, hence the term staircase, is the traditional stair for houses of two or more floors where the need for

resistance to fire does not dictate the use of concrete. Each flight of a staircase is made up (cased) in a joiner's shop as a complete flight of steps, joined to strings. Landings are constructed on site and the flight or flights are fixed in position between landings and floors.

Timber stair construction

The members of the staircase flight are string (or stringers), treads and risers. The treads and risers are joined to form the steps of the flight, and are housed in or fixed to strings whose purpose is to support them. Because the members of the flight are put together like a box, the boards can be thin and yet strong enough to carry the loads normal to stairs. The members of the flight are usually cut from timbers of the following sizes: treads 32 or 38 mm, risers 19 or 25 mm and strings 38 or 44 mm. Figure 9.15 is an illustration of a flight of a staircase with some of the treads and risers taken away to show the housings in the string into which they fit and the construction of a landing.

Joining risers to treads
The usual method of joining risers to treads is to cut tongues on the edges of the risers and fit them to grooves cut in the treads, as illustrated in Figure 9.16.
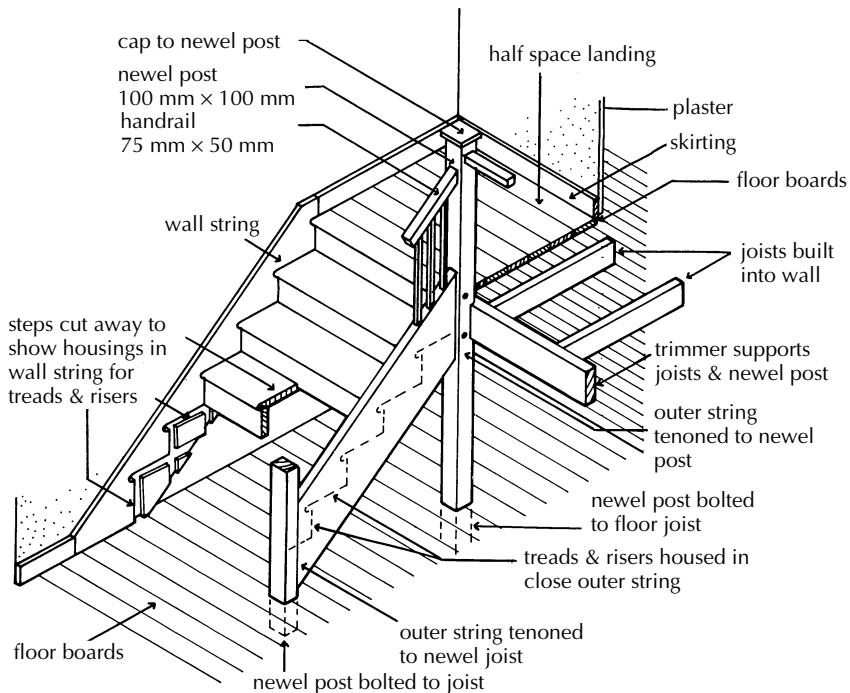
Figure 9.15   Lower flight of half turn staircase.
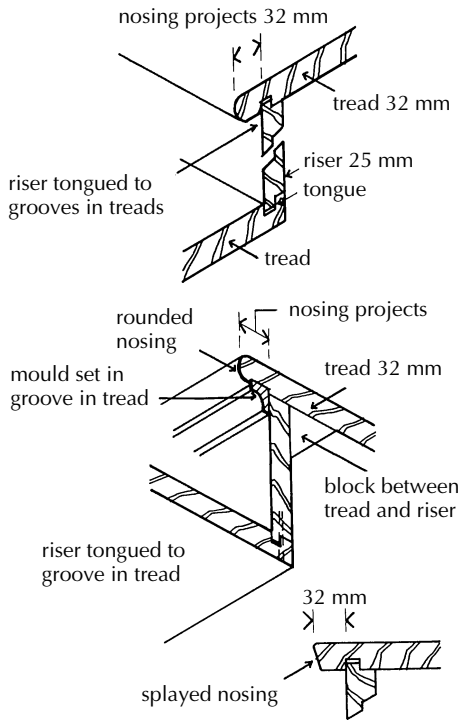
Figure 9.16 Method of jointing risers to treads.

Another method is to butt the top of the riser under the tread with the joint between the two, which would otherwise be visible, masked by a moulded bead housed in the tread, as illustrated in Figure 9.16. The tread of the stair tends to bend under the weight of people using it. When a tread bends, the tongue on the bottom of the riser comes out of the groove in the tread and the staircase 'creaks'. To prevent this it is common practice to secure the treads to the risers with screws (Figure 9.16). The nosing on treads usually projects 32 mm, or the thickness of the tread, from the face of the riser below. A greater projection than this would increase the likelihood of the nosing splitting away from the tread and a smaller projection would reduce the width of the tread. The nosing is rounded for appearance. Figure 9.16 illustrates the more usual finishes to nosings.

Strings, treads and risers
Strings (stringers) are cut from boards 38 or 44 mm thick and of sufficient width to contain and support the treads and risers of a flight of steps. Staircases are usually enclosed in a stair well. The stair well is formed by an external wall or walls and partitions, to which the flights and landings are fixed. The
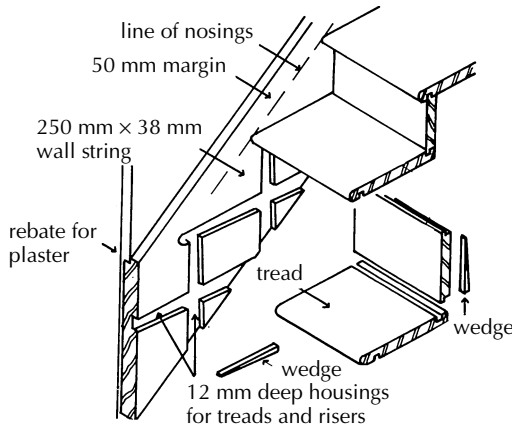
Figure 9.17   Housing treads and risers in close string.

string of a flight of steps, which is fixed against a wall or partition, is termed the wall string and the other string, if it is not fixed to a wall, is the outer string.

A string, which encloses the treads and risers it supports, is termed a close or closed string. It is made wide enough to enclose the treads and risers and its top edge projects some 50 or 63 mm above the line of the nosings of treads. The width of the string above the line of nosings is described as the margin. Figure 9.17 shows a closed string. A string 250 or 280 mm wide is generally sufficient to contain steps with any one of the dimensions of rise and going and a 50 mm margin. Wall strings are generally made as close strings so that wall plaster can be finished to them for a neat appearance. Outer strings can be made as closed strings or as open (cut) strings. The ends of the treads and risers are glued and wedged into shallow grooves cut in closed string. The grooves are cut 12 mm deep into strings and tapering slightly in width to accommodate treads, risers and the wedges, which are driven below them, as illustrated in Figure 9.17.

Angle blocks – glue blocks
After the treads and risers have been put together and glued and wedged into the string, angle blocks are glued in the internal angles between the underside of treads and risers and treads and risers and string. Angle glue blocks are triangular sections of softwood cut from say 50 mm square timber and each 120 mm long. Their purpose is to strengthen the right-angled joints between treads, risers and strings. Three or four blocks are used at each junction of tread and riser and one at junctions of treads, risers and string. Angle blocks are shown in Figure 9.18.
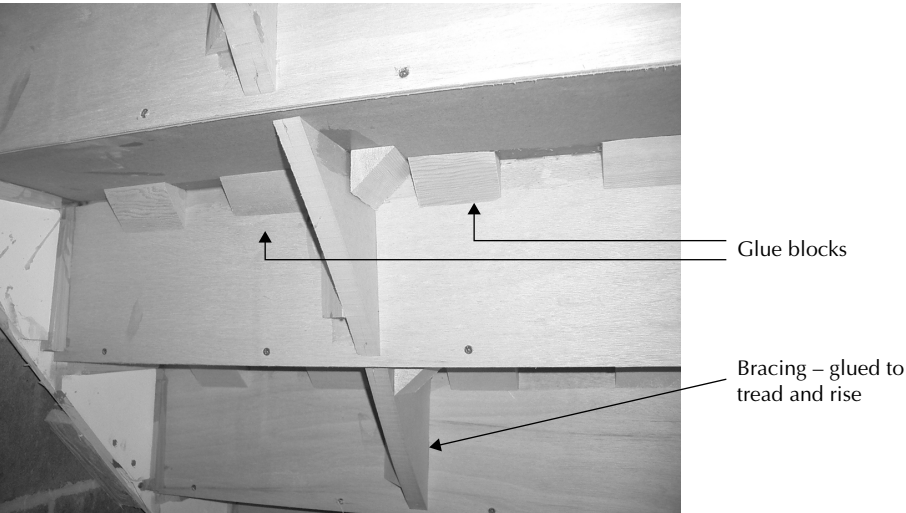
A   Prefabricated timber stair – glue blocks

Glue blocks

Bracing – glued to
tread and rise

Tread and riser inserted into
rebate in wall string

Wedges secure the treads
and risers in position

String plugged and
screwed to wall

Packing used to securely
position stair
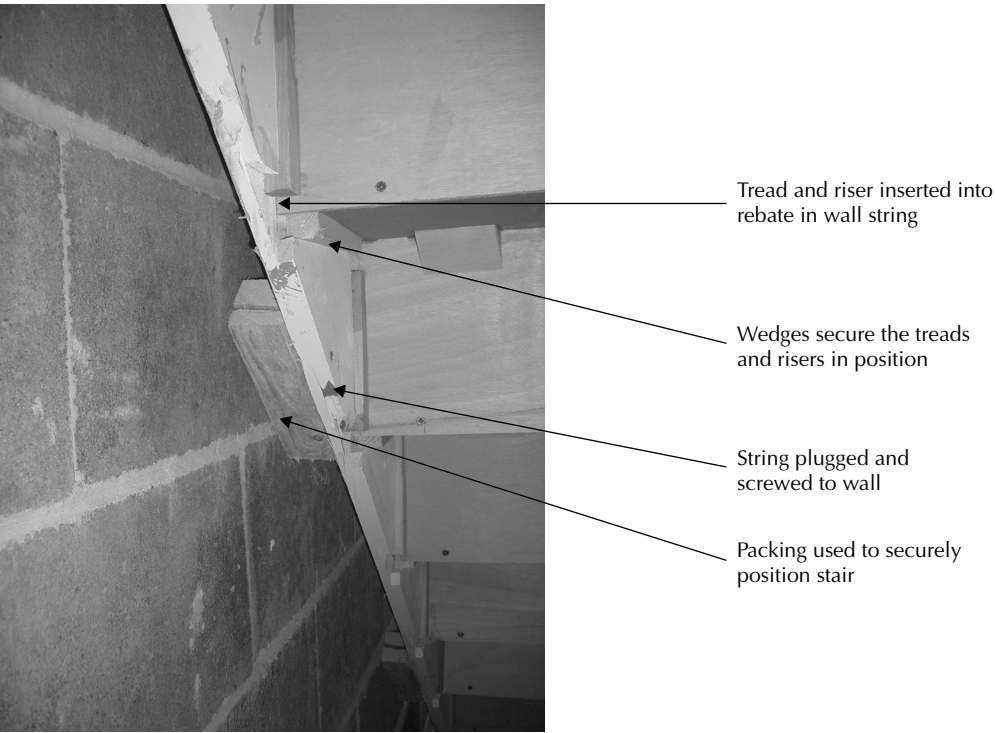
B   Fixing to wall and wedges

Photograph 9.3   Glue blocks and wedges.
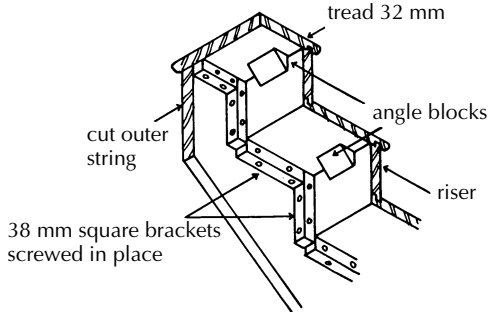
Figure 9.18   Underside of flight to show fixing of treads, and risers to cut outer string.

Cut or open string

A closed outer string does not show the profile of the treads and risers it encloses. Looking from the side of the staircase, only a single straight string with no steps in it can be seen. Alternatively, strings can be cut so that the profile of the steps can be seen. This type of string is termed a cut or open string. Because more labour is involved, a flight with a cut string is more expensive than one with closed strings. As the string is cut to the outline of the treads and risers they cannot be supported in housings in the string and are secured to brackets screwed to both treads and risers and string, as illustrated in Figure 9.18. It is difficult to cut a neat nosing on the end grain of treads to overhang the cut string, so planted nosings are fitted as shown in Figure 9.19. The planted nosings are often secured to the ends of treads by slot screwing. This is a form of secret fixing used to avoid having the heads of screws exposed.
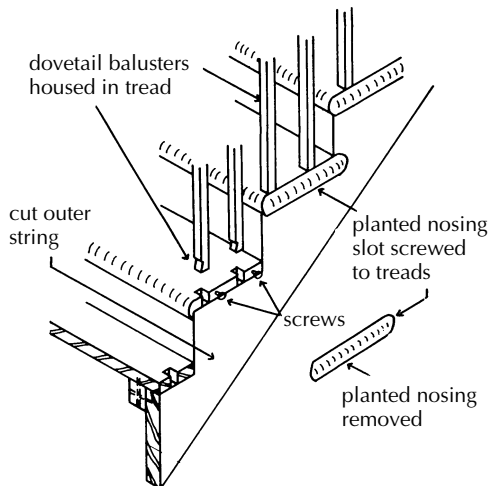
Figure 9.19   Cut string.
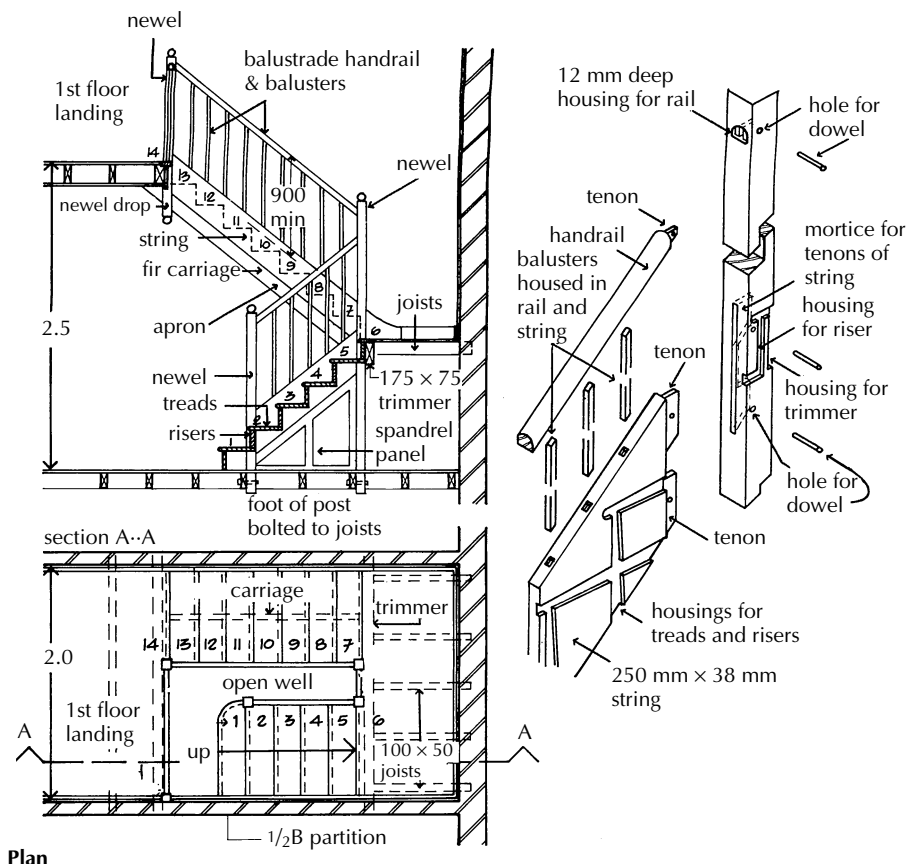
Figure 9.20   Half turn open well staircase.

Landings – half space (turn) landing

A half space landing is constructed with a sawn softwood trimmer which supports sawn softwood landing joists or bearers and floorboards, as illustrated in Figure 9.20. As well as giving support to the joists of the half turn landing, the trimmer also supports a newel or newel posts. Newel posts serve to support handrails and provide a means of fixing the ends of outer strings.

Newel posts

The newel posts are cut from 100×100 mm timbers and are notched and bolted to the trimmer. The outer string fits to mortices cut in the newel, as illustrated in Figure 9.20. For appearance, the lower end of the newel post is usually about 100 mm below the flights and moulded. As it projects below the stair it is called a drop newel.

Open balustrade

The traditional balustrade consists of newel posts, handrail, and timber balusters, as illustrated in Figure 9.20. The newel posts at half turn landings and at landings at first floor level are housed and bolted to trimmers. These newels are fixed in position so that the faces of the risers at the foot and head of flights are in line with the centre line of the newel.

Handrail

The top of the handrail is usually fixed a minimum height of 900 mm vertically from the pitch line to the top of the handrail and 900 mm above landings for domestic stairs in a single house and 900 to 1000 mm above the pitch line for other stairs. The handrail is cut from 75×50 mm timber, which is shaped and moulded. The ends of the handrail are tenoned to mortices in the newels.

Balusters

Balusters may be 25 or 19 mm square or moulded. They are either tenoned or housed in the underside of the handrail and tenoned into the top of closed strings or set into housings in the treads of flights with cut string, as shown in Figure 9.19. To prevent children under 5 years of age from becoming stuck between them, balusters should be so spaced that a 100 mm sphere cannot pass between them.
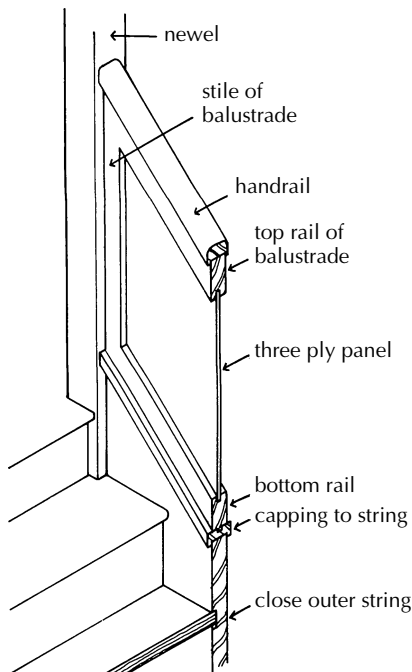
Figure 9.21   Enclosed balustrade.

The traditional balustrade of vertical balusters, either plain or moulded, may not provide a satisfactory appearance for some situations, for example, enclosed glass panelled balustrades with the glass set in a metal channel above the pitch line to concrete steps or stairs and set into a channel fixed under or below a handrail. An enclosed balustrade to a close string stair is illustrated in Figure 9.21, with a plywood panel set in a softwood frame fixed between the top of a close, outer string and the underside of the handrail.

Bullnose and curved steps

For the sake of appearance the bottom step of a timber staircase may be framed to project beyond the newel post and be shaped as either a quarter or a half circle as illustrated in Figure 9.22. By projecting from the enclosing strings into the floor the bottom step gives the sense of the stair belonging to the floor as well as the staircase. The bullnose, quarter circle and the rounded, half circle, end steps are made by cutting a riser made from a veneer of thin wood which is shaped around three curved blocks as illustrated in Figure 9.23. The tread is cut with a projecting nosing to return around the shaped bottom step.

Spandrel

The triangular space between the underside of the lower flight of a stair and the floor is the spandrel. It may be left open and be a nuisance to keep clean or more usually it is enclosed with spandrel filling (boarded up) or closed with timber framed panelling as illustrated in Figure 9.22. Where the length of the

Figure 9.22   Shaped steps.

riser cut to veneer
thickness, shaped
around blocks

wedges

block on end
of riser

shaping blocks
screwed to riser
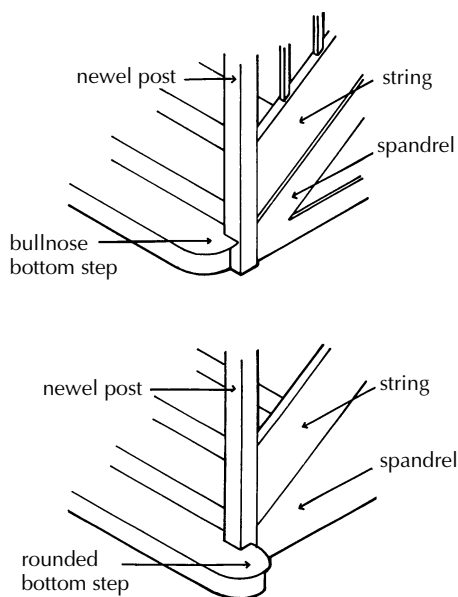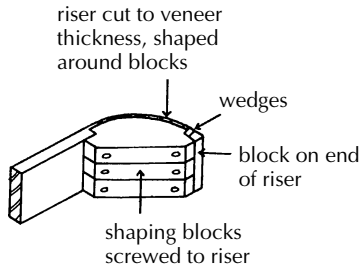
Figure 9.23   Bullnose step.

spandrel filling is sufficient, the panelling may be framed around a door so that the spandrel space below the stair may be used for storage.

Carriage

A sawn softwood carriage is usually fixed below flights of a staircase to give support under the centre of each step. The fir (softwood) carriage illustrated in Figure 9.24 is 100 × 6 × 75 mm in section and nailed to landing trimmers or joists for support with the top surface of the carriage directly under the angle of junction of treads and risers. Short off cuts from 175 × 25 mm boards are nailed alternate sides of the carriage, so that the top edge of these brackets bears under treads to reduce creaking of the stair.

Where the soffit of flights of staircases is to be plastered, two additional fir carriages should be fixed, one next to the wall and the other next to the outer string as fixing for plasterboard.

Winders

Winders is the name given to tapered treads that wind round quarter or half turn stairs in place of landings to reduce the number of steps required in the

carriage fixed
to trimmer

carriage

rough brackets
nailed to carriage

bottom of carriage
fixed to floor
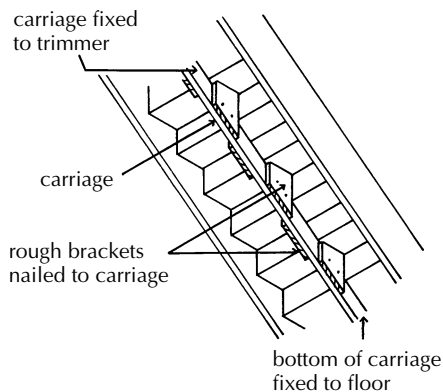
Figure 9.24   Underside of flight showing carriage and brackets.
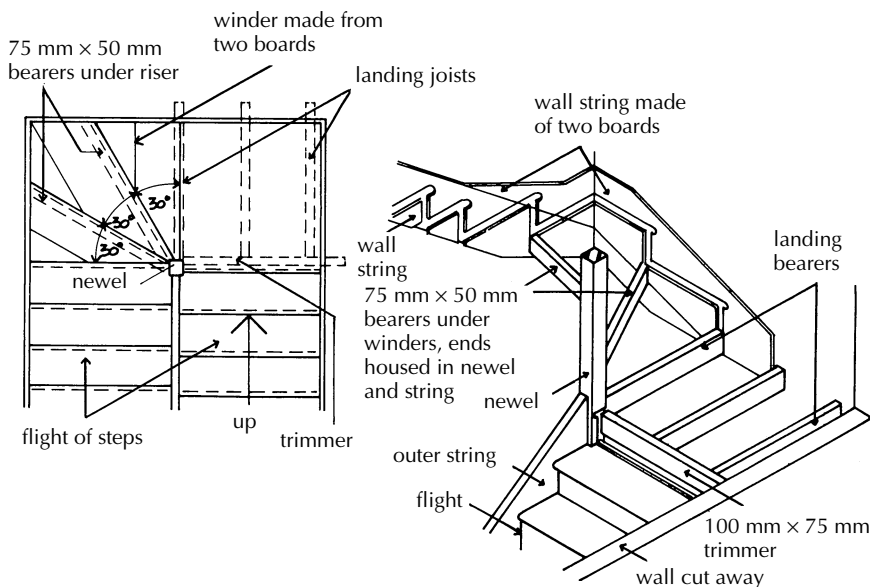
Figure 9.25 Winders and quarter space landing.

rest of the stair and to economise on space. These winders may be used in domestic stairs, although they may present a hazard to the young and elderly and are not recommended for use in means of escape stairs or stairs in public buildings. The winders illustrated in Figure 9.25 are constructed as three taper treads at the quarter turn of a half turn stair with a quarter turn landing leading down to the lower flight.

The newel post may be continued down to and supported at the floor below so that it may support the trimmer for the quarter space landing and the bearers for the winders. The treads of the winders are made of two boards tongued and grooved together. To support the edge of winders, 75×50 mm bearers are housed in the newel post and wall string. Because of the extra width of the tread of winders where they are housed in wall strings, the wall string has to be made of two boards into which both treads and risers are housed in 12 mm grooves and wedged and glued.

Open riser or ladder stair

An open riser or ladder stair consists of strings with treads and no risers so that there is a space between the treads, with treads overlapping each other by at least 16 mm (they are not suitable for disabled use). Various materials and forms of construction are used for exposed open riser stairs, such as wood strings, treads and handrail, reinforced concrete strings and treads, reinforced
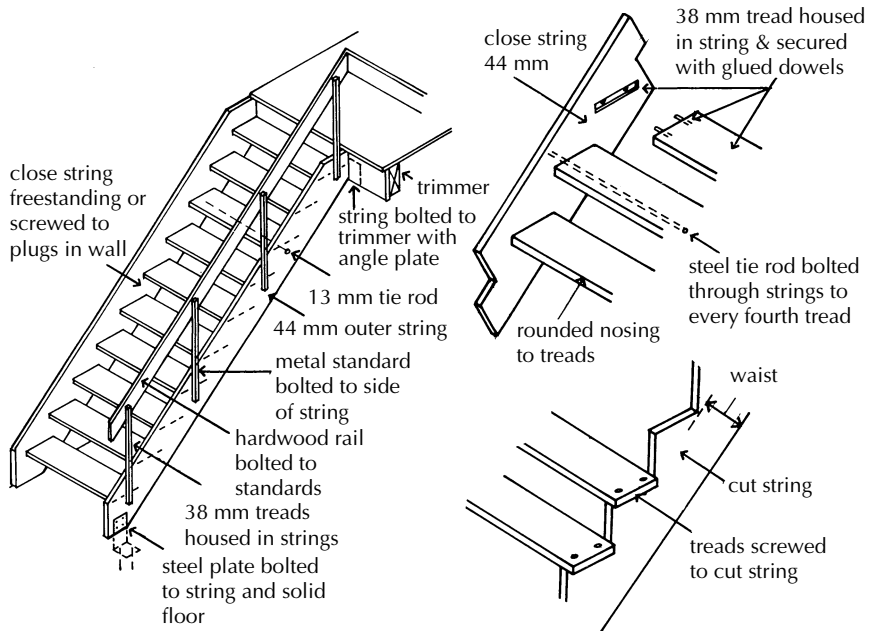
Figure 9.26   Open riser stair with closed or cut string.

concrete central carriage with cantilever treads, and steel strings and treads to a steel handrail supporting glass treads hung from the handrails.

More traditional open riser stairs are illustrated in Figure 9.26. The strings may be either close or cut to the outline of the treads. The treads should be cut from 38 or 44 mm thick timbers, which are housed in closed strings and secured in position with glued wood dowels. To strengthen the fixing of the treads to the strings against shrinkage and twisting, 10 or 13 mm tie rods, one to every fourth tread, are bolted under the treads through the strings. The strings are fixed to the floor with steel plates, which are bolted to the sides of the timber strings and bolted to timber trimmers or cast into concrete floors.

Open riser timber stair

Open riser timber stairs are often constructed as straight flight stairs between floors and there is no newel post to provide a fixing for the handrail. The handrail and balustrade are fixed to the sides of the strings, as illustrated in Figure 9.26.

Gaps in stairways

Where it is likely that children under the age of five are likely to use the stairway, any gap or opening must not allow a 100 mm sphere to pass through it. This is to prevent a child's head from becoming lodged between parts of a stairway. Thus, openings in open stairways and between balusters should be less than 100 mm.

Protective sheet fixed over
stair flight

Temporary treads tacked
(securely) in place

Photograph 9.4   Temporary protection of timber stairways.

Protection of stairs during construction
The importance of protecting stairs and ramps from damage during the construction period should not be under estimated. Stairs and ramps constructed insitu will be used by construction personnel and therefore must be protected to ensure that the surface finish is not damaged before the building is complete. Although pre-fabricated staircases can be installed much later in the construction process, it is common practice to install them as early as possible to provide safe access to the upper floor. Where stairs are used during the construction period they should be protected with temporary treads. Temporary timber treads can be simply tacked (but securely fixed) in place until the construction period is finished. The whole stairway should also be safely covered with a protective membrane, such as building paper.

9.5 Stone stairs

Stone stairs were constructed of steps of natural stone of rectangular or triangular section built into an enclosing wall so that each stone was bedded on the stone below in the form of a stair. Each stone was built into the wall of the
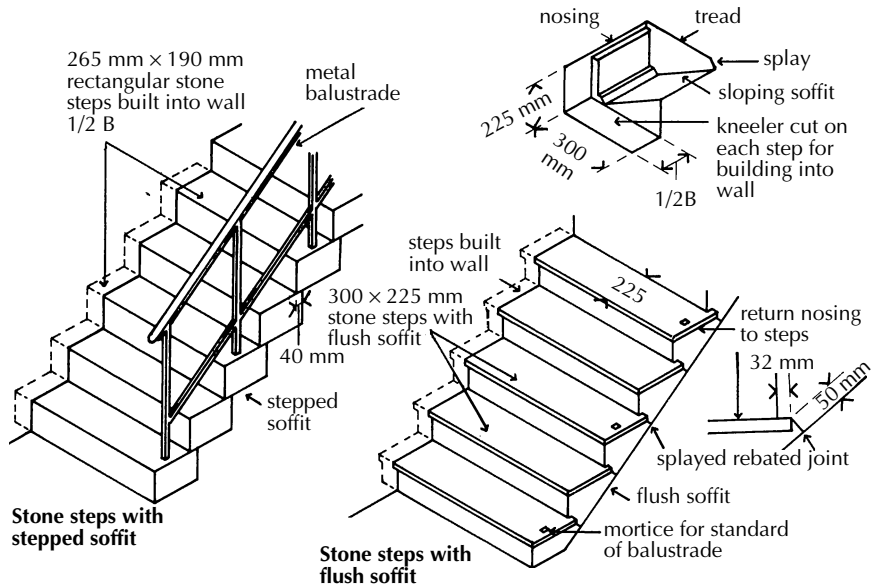
Figure 9.27   Stone steps.

stair well from which it cantilevered and took some bearing on the stone below in the form of a prop cantilever. The steps were either of uniform rectangular section with a stepped soffit or rectangular section cut to triangular section to form a flush soffit, as illustrated in Figure 9.27. The ends of the crude rectangular section steps were built into a wall. The ends of the triangular section steps had their rectangular ends built in. These steps had splayed rebated joints and nosings cut on the edge of the tread surface. Landings were constructed with one or more large slabs of natural stone built into enclosing walls and bearing on the step below. Because of the cost of natural stone this type of stairs is now made of cast stone or cast concrete which is usually reinforced and cast in the same sections as those illustrated for natural stone, or as a combined tread and riser with a rectangular end for building into walls and a stepped soffit.

9.6 Reinforced concrete stairs

With the use of the reinforced concrete skeleton frame, as one of the principal structural frames for the majority of buildings of more than three floors, a reinforced concrete stair, either cast insitu, precast or a combination of insitu and precast, is used. A reinforced concrete stair has better resistance to damage by fire than a conventional timber staircase and is used for access and a means of escape stairs in most buildings of more than three storeys. The width, rise,
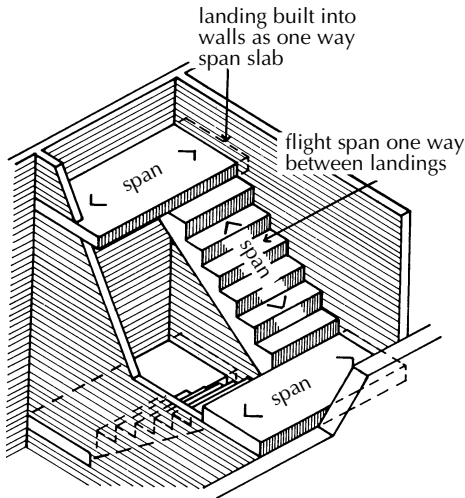
Figure 9.28   Inclined slab stair.

going and headroom for these stairs and the arrangement of the flights of steps as straight flight, quarter turn, half turn and geometrical stairs is the same as for timber stairs. The usual form of a reinforced concrete stair is as a half turn (dog leg) stair either with or without an open well. The construction of the stair depends on the structural form of the building and the convenience in casting the stair insitu or the use of reinforced concrete supports and precast steps.

Concrete stair construction

Concrete stairs, which span between landings
Where there are load bearing walls around the stair it is generally economic to build the landings into the side walls as one-way spanning slabs and construct the flights as inclined slabs between the landings as illustrated in Figure 9.28. This form of stair is of advantage where the enclosing walls are of brick or block as it would involve a great deal of wasteful cutting of bricks or blocks were the flights to be built into the walls and the bricks or blocks cut to fit to the steps.

Concrete stairs – cranked slab
As an alternative, the stair may be designed and constructed as a cranked (bent) slab spanning through landing, flight and next landing as one slab with no side support as shown in Figure 9.29A. This is a more costly construction than using the landings as slabs to support the flight. The flights have a greater span and therefore the cost of the stair is greater. This form of construction is used where the landings cannot gain support each side of the stair.
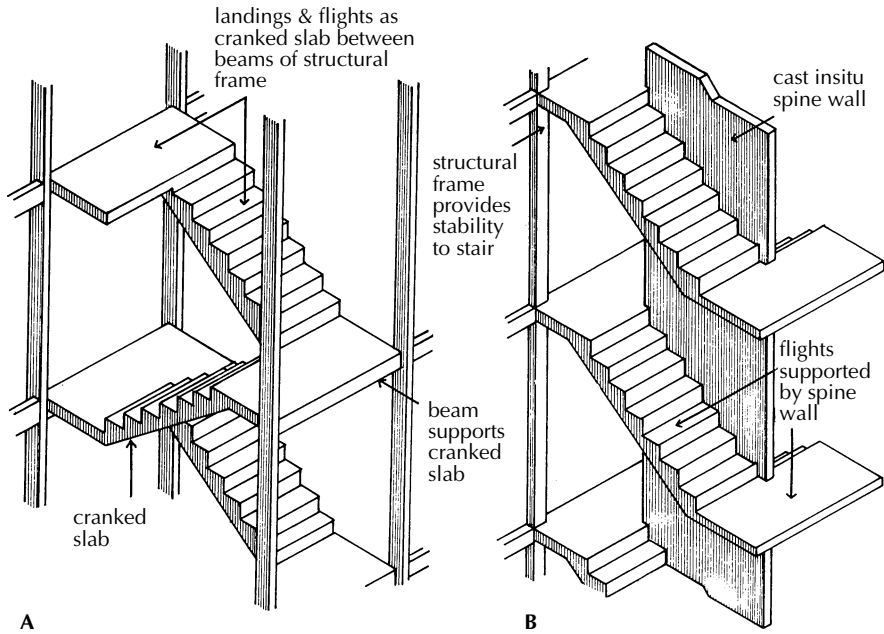
Figure 9.29   (A) Cranked slab stair. (B) Cantilevered spine wall stair.

String and trimmer concrete stair

Another construction is to form a reinforced concrete frame of beams to landings supporting inclined beams to flights, as illustrated in Figure 9.30. The landing beams are supported by side walls or the beams of a frame and in turn support inclined beams that support the steps. This is a somewhat clumsy
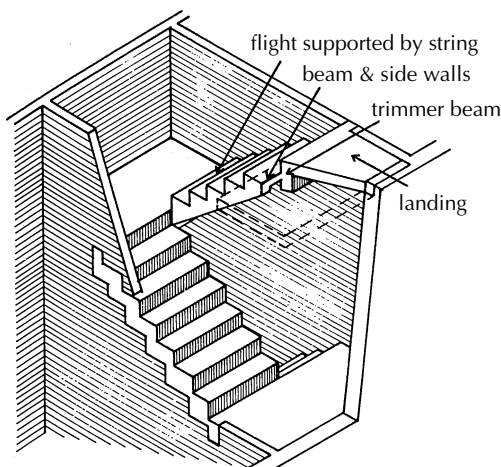
Figure 9.30   String and trimmer stair.

form of construction with a very untidy soffit or underside to the stair. It is best suited to the use of precast concrete steps that bear on the inclined beam under the flight with step ends built into enclosing walls or on two inclined beams, and the use of precast landings.

Concrete stairs cantilevered from a central spine

Where a reinforced concrete half turn stair is constructed around a reinforced concrete centre spine wall between the flights, the stair may be constructed to cantilever from this spine wall, as illustrated in Figure 9.29B, or partly cantilever from the spine wall and be supported by the enclosing frame or walls.

Reinforcement for concrete stairs

The reinforcement of a concrete stair depends on the system of construction adopted. The stair illustrated in Figure 9.31 is designed and built with the
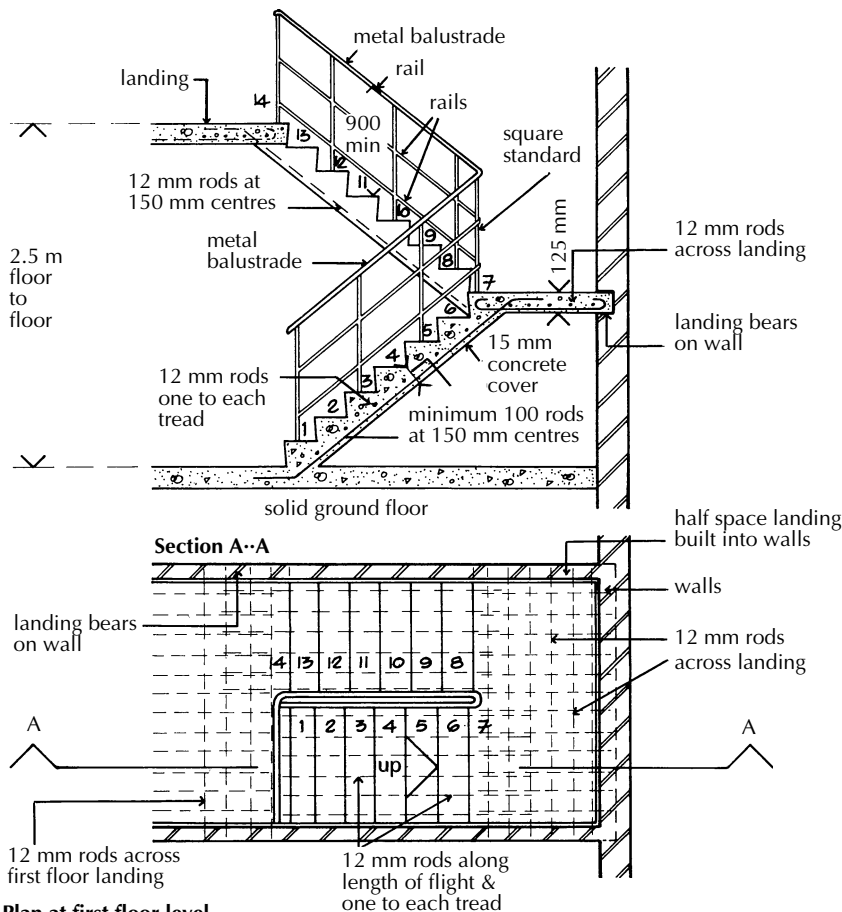
Figure 9.31   Half turn reinforced concrete stair.

landings built into the enclosing walls as a two-way slab, and an inclined slab as flights spanning between landings independent of the side walls. The main reinforcement of the landings is both ways across the bottom of the slab, and the main reinforcement of the flights is one way down the flights. The effective depth of the inclined slab that forms the flights is at the narrow waist formed in section by the junction of tread and riser and the soffit of the flight. It is this thickness of the slab that has constructional strength and the steps play no part in supporting loads. The reinforcement has to have a cover of concrete around it to inhibit rust and protect steel rods against damage by fire.

Balustrade

The balustrade to a stone, cast stone or reinforced concrete stair is usually of metal, the uprights of which are either bolted to the sides of the flights to studs cast or grouted into the material or bolted through the material or set in mortices either cast or cut in the material. These vertical metal supports or standards in turn support rails as a balustrade for security and a handrail.

To provide maximum rigidity for the uprights that support a balustrade and handrail for stone or concrete stairs and landings, the uprights should be bolted
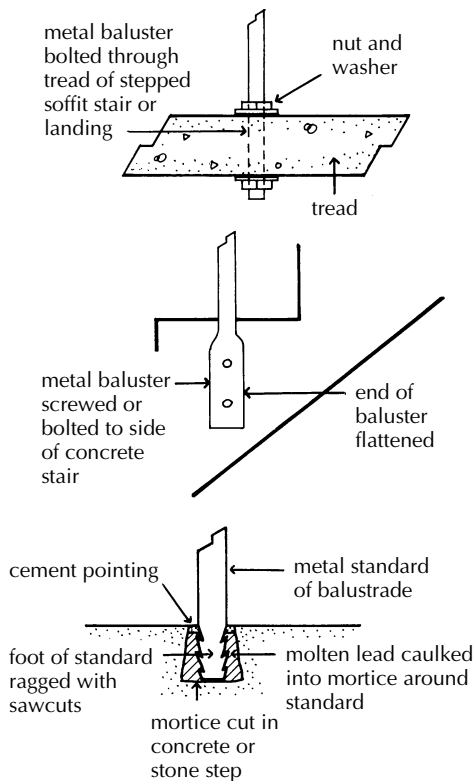
Figure 9.32   Setting metal standard in stone or concrete step.
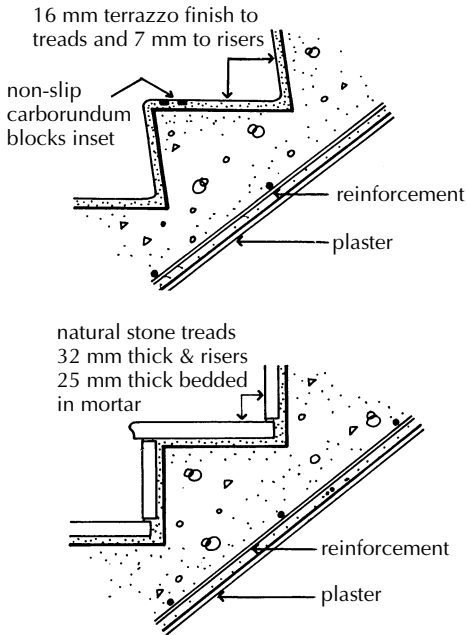
Figure 9.33   Finishes to concrete steps.

through the thickness of the flights and landings as illustrated in Figure 9.32. The metal uprights are bolted with nuts and washers through the depth of the stair. Uprights at some 900 to 1200 mm intervals will support a frame fixed just above pitch line and up to and including a handrail.

As an alternative fixing, for flush sloping soffit flights for example, the uprights may be secured by expanding bolts to the side of a reinforced concrete stair as illustrated in Figure 9.32. The traditional method of fixing the metal uprights, standards or balusters to natural stone stairs and landings is by fixing the end of the verticals into a mortice cut in the stone. The ragged end of the verticals is then set in the mortice and molten lead is run into the mortice and caulked (rammed) to complete the joint. As this fixing for the uprights of a balustrade is not so rigid or secure as bolting through, the uprights have to be at fairly close intervals of 400 to 600 mm to support the balustrade frame and handrails.

Hard, durable, natural stone steps and landings may be left as a natural finish for the benefit of the appearance of the stone. Even the hardest natural stone will become scuffed and dirty in time and is laborious to keep clean. Usually stone and concrete stairs are given an applied finish to create a surface that is easy to clean and is visually more attractive. Insitu or precast terrazzo is often used for its appearance and ease of cleaning, with carborundum inserts as a non-slip surface, as illustrated in Figure 9.33. Wood treads of hardwood screwed to plugs in each step provide an attractive, durable and quiet-in-use

surface. Stone treads and risers may be bedded as a surface finish for reinforced concrete stairs, as illustrated in Figure 9.33.

9.7 Structural glass stairs

Glass stairs, handrails and barriers have become increasingly common in recent years. This is partly down to architectural fashion, but mainly a result of considerable advances in the strength of glass used for structural purposes. Although aesthetics play a considerable part in the choice of a glass stairway there are some functional reasons why glass may be used, especially when used in handrails and balustrades/guarding.

In many public buildings, such as airports and other large complexes, it has become increasingly important to be able to see the movement of people and their belongings. Balustrades made out of concrete, steel or timber may obscure vision and provide a place where people can hide, become trapped or encounter difficulty without others being aware. The increasing threat of terrorism also means that places where bombs can be hidden should be avoided. A solid glass panel can also be useful in buildings that are used by children, partly because they are difficult to climb and partly because they remain visible behind the panels.

9.8 Ramps

Ramps should be designed to form as gentle an incline as possible, avoiding steep gradients that will create difficulties for users. Restricting the incline of the slope allows greater ease up the slope and controls the speed at which people descend. Landings may be required to allow the users and their helpers to rest during the ascent or descent of the ramp. The landing must allow adequate space for users to rest and also allow others to pass safely.

Internal ramps

Criteria for internal ramps (Figure 9.34) are:

❑ Slip resistant surface, frictional resistance of ramp and landing must be similar
❑ Visual colour contrast between landing and ramp
❑ Surface width of at least 1.5 m
❑ If the ramp provides means of escape the number of persons expected to use the ramp and the type of building need to be considered to determine the width (see Table 9.1)
❑ Maximum gradient (see Table 9.3)
❑ No flight should have a going greater than 10 m, or a rise of more than 500 mm

Photograph 9.5   Examples of structural glazing used in stairs.
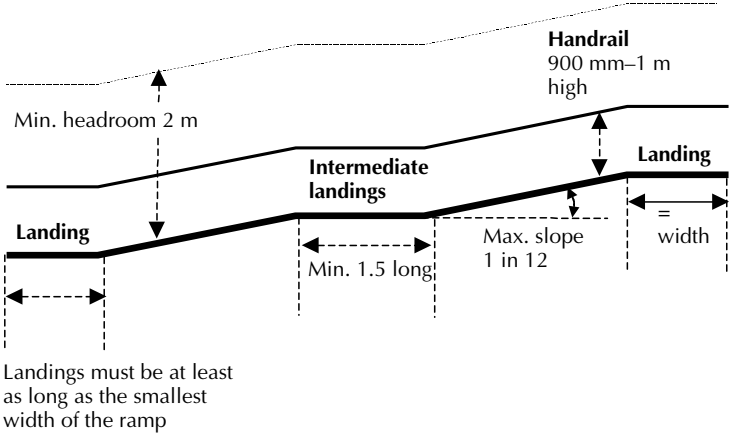
Figure 9.34   Internal ramps – positioning of landings.

❏ The ramp must have a top and bottom landing at least as long as the narrowest width of the ramp
❏ All ramps should have clear headroom of 2 m
❏ Handrails should be between 900 mm and 1 m high on the flight and 900 mm to 1100 mm on the landing
❏ Handrails should extend 300 mm beyond the top and bottom of the ramp
❏ Handrails should be on both sides
❏ Landings at the foot and head must be at least 1.2 m long
❏ Intermediate landings must be minimum length of 1.5 m and be clear of doorways
❏ Intermediate landings should be a minimum of 1.8 m wide and 1.8 m long, where they are required as passing places (when wheelchair users cannot see from one end of the ramp to the other, or the ramp has three flights).

External ramps providing access to a building

The requirements imposed by Approved Document K for external ramps are more stringent than for those used inside buildings; obviously the exposure to the weather is a determining factor. The following provide a summary of the requirements imposed by section K on ramps that are used in situations other than in buildings:

❏ Ramped access should be clearly signposted
❏ Signs also required to warn users of hazard, when rise is greater than 300 mm
❏ Risk is greatest at the head of the ramp, signage should be sufficient to allow a person to stop before the ramp
❏ Max gradient as in Table 9.3
❏ No flight has a going greater than 10 m or rise more than 500 mm
❏ Alternative access must be provided if total rise is greater than 2 m (e.g. a lift)
❏ Slip resistant surface
❏ Visual colour contrast between landing and ramp
❏ Frictional characteristics of landing and flight must be similar

Table 9.3   Limits of ramp gradient (Approved Document M).

Ramp gradients between landings		
Going of flight (m)	Max. gradient	Min. rise (mm)
10	1:20	500
5	1:15	333
2	1:12	166

For goings between 2 and 10 m, it is acceptable to interpolate between the maximum gradients.

❑ Corduroy hazard warning surface should be provided at the top and bottom
❑ Width of ramp must be at least 1.5 m
❑ Must have top and bottom landing, minimum length 1.2 m, clear of obstructions
❑ Intermediate landings must be minimum length 1.5 m, clear of obstructions
❑ Intermediate landings used as passing places must be a minimum of 1.8 m long and 1.8 m wide
❑ Landings are level, subject to maximum gradient of 1:60 and maximum cross fall of 1:40
❑ Handrails on both sides, should extend 300 mm beyond the ramp
❑ Handrails should provide a visual contrast against background and not be cold to the touch
❑ Handrail dimensions are as those for disabled stairs (see Figure 9.9)

10   **Surface Finishes**

Surface finishes are particularly important. Finishes form the interface between building users and the building and hence affect the way in which we interact and perceive our built environment. Surfaces are seen, touched and smelt by building users. Colour, or the lack of it, affects our psychology and the atmosphere of our buildings. Materials give off scent and this too will influence our internal environment and may affect our health. Given the wide variety of finishes available the materials used to form a finish are quite extensive. In this volume we have confined ourselves to the finishes most commonly found in domestic properties and small office developments.

10.1 Functional requirements

Types of finish

There are two different types of finish to the building fabric: those inherent in the material and those applied to a background.

Inherent finishes

Many materials such as timber, stone, brick and glass provide a natural finish without any need for further work – an inherent finish. Attention to joints, fixings and the quality of work is critical (because they will not be covered up). Where brickwork and blockwork is to be left fair-face, rather than be plastered, it is important to specify this so that the quality of the workmanship and joints are built to an appropriate quality. Carefully chosen, materials with an inherent finish may help to reduce construction time and initial construction costs. Furthermore, the use of materials with an inherent finish may be an important consideration when disassembling the building and recycling materials at a future date, since the material has not been compromised by the application of a finish.

Applied finishes: ecological consideration

Application of materials to existing backgrounds, such as plaster to a wall or paint to timber, is an applied finish. The durability of the finish will depend upon the material properties of the finish and the material it is applied to, as well as the bond between the two materials. Ecological design goals aim to minimise the pollution from applied finishes. Petrochemical paints, stains and

varnishes should be avoided and preference given to products with natural pigments that are not harmful to animals, plants or people.

Functional requirements

The primary function of a surface finish is to provide a durable, visually attractive and low maintenance surface to floors, walls and ceilings. There may be differences between the functional requirements of the finish depending on whether it is an external or internal finish as detailed below.

External finishes
External finishes are important in determining the aesthetic appeal of the building. The external finishes will also, in conjunction with the detailing, determine how the building will weather over time. Thus the quality of the materials used for external finishes and the manner in which they are applied will determine the durability of the building fabric. Functional requirements are:

❑ Aesthetic appeal
❑ Durability
❑ Strong mechanical or chemical bond to structural substrate
❑ Flexibility, the ability to withstand thermal and moisture movement (via control joints)
❑ Health and safety considerations

Internal finishes
Internal finishes are important in creating a sense of place and in helping to ensure a healthy indoor environment. As we spend a great deal of time within buildings, the quality of the internal environment is particularly important in ensuring a sense of wellbeing and enjoyment. Materials will be touched, experienced visually and will give off scent, which combined with furnishings and appliances will influence our perception of the space in which we live or work. Functional requirements are:

❑ Aesthetics
❑ Durability and flexible ability to withstand thermal and moisture movement
❑ Ease of maintenance and cleaning
❑ Strong mechanical or chemical bond to structural substrate
❑ Expel water from the surface that forms as condensation (particularly in kitchens and bathrooms)
❑ Prevent and resist mould growth or insect attack
❑ Provide visual finish, high levels of contrast (e.g. nosing on stairs)
❑ Tactile or touch sensitive finish as an aid to those with visual difficulties

10.2 Floor finishes

A floor finish should be level, reasonably resistant to the wear, be capable of being maintained and remain in a safe condition during its designated design life and capable of being easily cleaned. For specific areas of buildings, additional requirements may be that the surface should be non-slip, smooth for cleaning and polishing, resistant to liquids and chemical spillages, seamless for hygiene, etc. There is no one finish that will satisfy the possible range of general and specific requirements. There is a wide range of finishes available from which one may be selected as best suited to a particular requirement. For the small floor areas of rooms in houses and flats the choice of floor finish is dictated largely by appearance and ease of cleaning. For the larger floor areas of offices, public and institutional buildings, ease of cleaning is a prime consideration where power operated cleaning and polishing equipment is used.

Finishes to concrete floors

It is convenient to make a broad general classification of finishes to concrete floors (described in Chapter 4) as:

❑ Jointless
❑ Flexible thin sheet and tile
❑ Rigid tiles and stone slabs
❑ Wood and wood based

Jointless floor finishes

This group includes the cement- and resin-based screeds and mastic asphalt that are laid while plastic and do not show joints and seams other than movement joints where necessary.

Cement screeds
A cement and sand screed finish to a concrete floor may be an acceptable, low cost finish to small area floors of garages, stores and outhouses where the small area does not justify the use of a power float and considerations of ease of cleaning are not of prime importance. Premixed, cement and sand screed material reinforced with polymer fibre is available; the fibre reinforces against drying, shrinkage and cracking. To produce improved surface resistance to wear and resistance to the penetration of oils and grease a dry powder of titanium alloy with cements may be sprinkled on to the wet surface of concrete or screed and trowelled in.

Granolithic paving

The cement screed finish to the floors of factories, stores, garages and other large floor areas, which have to withstand heavy wear, is granolithic paving or screed.

Granolithic paving consists of a mixture of crushed granite, which has been carefully sieved so that the particles are graded from coarse to very fine in such proportions that the material, when mixed, will be particularly free of voids or small spaces, and when mixed with cement will be a dense mass. The usual proportions of the mix are $2\frac{1}{2}$ of granite chippings to 1 of cement by volume. These materials are mixed with water and the wet mix is spread uniformly and trowelled to a smooth flat surface. When this paving has dried and hardened it is hard wearing. There are a number of additives variously described as 'sealers' or 'hardeners', that may be added to the granolithic mix to produce improved resistance to surface wear.

Anhydrite floor finish

Premixed, dry bagged screed material of anhydrite and sand is used as a floor finish. Anhydrite is a mineral product of heating gypsum that will, when mixed with water, act as a cement to bind the grains into a solid mass as the material dries and hardens. The advantage of anhydrite is that it readily combines with water and does not shrink and crack as it dries out and hardens. The wet mix of anhydrite and sand may be pumped and spread over the concrete base as a self-levelling screed or spread and trowelled by hand. The material may be pigmented. A disadvantage of the material is that it fairly readily absorbs water and is not suited to use in damp situations.

Resin based floor finish

A range of resin emulsion finishes is available for use where durability, chemical resistance and hygiene are required in laboratories, hospitals and food preparation buildings. This specialist application finish is composed of epoxy resins as binders with cement, quartz, aggregates and pigments. The material is spread on a power floated or cement screed base by pumping and trowelling to a thickness of up to 12 mm. The aggregate may be exposed on the surface as a non-slip finish and as decoration. On larger floor areas it is used for the advantage of a seamless finish that can be cleaned by a range of power operated devices.

Polymer resin floor surface sealers

Polyester, epoxy or polyurethane resin floor sealers are specialist thin floor finishes used for their resistance to water, acids, oils, alkalis and some solvents. The materials are spread and levelled on a level power floated or screed surface to provide a seamless finish to provide an easily cleaned surface. Polyester resin, the most expensive of the finishes, is spread to a finished thickness of 2 to 3 mm to provide the greatest resistance. Epoxy resin provides a less exacting

resistance. It is sprayed or pumped to a self-levelling or trowelled thickness of 2 to 6 mm. Polyurethane resin, which has moderate resistance, can be spread on a somewhat uneven base by virtue of its possible thickness. It is pumped to be self-levelling for thin applications and trowelled for the thicker applications. Thicknesses of between 2 and 10 mm are used.

Mastic asphalt floor finish

Mastic asphalt serves both as a floor finish and a dpm. It is a smooth, hard-wearing, dust free finish, easy to clean but liable to be slippery when wet, and less used since the advent of the thin plastic tiles and sheets.

Flexible thin sheet and tile

Linoleum is made from oxidised linseed oil, rosin, cork or wood flour, fillers and pigments compressed on a jute canvas backing. The sheets are made in 2 m widths, 9 to 27 m lengths and thicknesses of 2.0, 2.5, 3.2 and 4.5 mm in a variety of colours. The usual thickness of sheet is 2.5 mm. Tiles 300 and 500 mm square are 3.2 and 4.5 mm thick. Linoleum should be laid on a firm level base of plywood or particleboard on timber floors or on hardboard over timber-boarded floors and on a trowelled screed on concrete floors. The material is laid flat for 48 hours at room temperature and then laid on adhesive and rolled flat with butt joints between sheets. Linoleum has a semi-matt finish, is quiet and warm underfoot and has moderate resistance to wear for the usual 2.5 mm thick sheets and good resistance to wear for the thicker sheets and tiles. Linoleum has been used instead of vinyl for the advantage of the strong colours available in the form of sheets and also in the form of decorative patterns by combining a variety of colours in various designs from cut sheet material, a characteristic that has seen the material experience a return to fashion more recently.

Flexible vinyl sheet and tiles

Polyvinylchloride (PVC), generally referred to as vinyl, is a thermoplastic used in the manufacture of flexible sheets and tiles as a floor finish. The material combines PVC as a binder with fillers, pigments and plasticisers to control flexibility. The resistance to wear and flexibility vary with the vinyl content, the greater the vinyl content the better the wear and the poorer the flexibility.

Vinyl sheet flooring has become the principal sheet flooring used where consideration of cost and ease of cleaning combine with moderate resistance to wear. Sheet thicknesses from 1.5 to 4.5 mm in widths from 1200 to 2100 mm are produced in lengths of up to 27 m. Foam backed vinyl sheet is produced to provide a resilient surface with the advantages of resilience and being quiet underfoot but at the expense of the material being fairly easily punctured. The material is extensively used in domestic kitchens and bathrooms and offices where a low cost, easily cleaned surface is suited to moderate wear.

The thin sheet material should be laid on a smooth, level screeded surface particularly free from protruding hard grains that might otherwise cause undue wear. The thicker, less flexible sheet may be laid on a power floated concrete finish. The sheets are bonded on a thin bed of epoxy resin adhesive and rolled to ensure uniformity of adhesion. For large areas of flooring the sheets may be heat welded to provide a seamless finish. A range of flexible vinyl tiles is produced in a variety of colours and textures in 225, 250 or 300 mm squares by 1.5 to 3 mm thicknesses. Various shapes of cut sheet may be used to provide single or multi-coloured designs.

Clay floor tiles

Natural clay floor tiles have been used for centuries as a hard, durable floor surface and finish for both domestic and agricultural ground floors. The two types of tile may be distinguished as floor quarries and clay floor tiles. The word quarry is derived from the French *carr*, meaning square.

Floor quarries
Floor quarries are manufactured from natural clays. The clay is ground and mixed with water and then moulded in hand operated presses. The moulded clay tile is then burned in a kiln. Manufacturers grade tiles according to their hardness, shape and colour. The first or best quality of these clay floor quarries is so hard and dense that they will suffer the hardest wear without noticeably wearing. Because they are made from plastic clay, which readily absorbs moisture, quarries shrink appreciably when burned, and there may be a noticeable difference in the size of individual tiles in any batch. The usual colours are red, black, buff and heather brown. Some common sizes are 100 × 100 × 12.5 mm thick, 150 × 150 × 12.5 mm thick and 229 × 229 × 32 mm thick.

Clay floor tiles
Where finely ground clay is used, the finished tiles are very uniform in quality and because little water is used in the moulding, very little shrinkage occurs during burning. The finished tiles are uniform in shape and size and have smooth faces. The tiles are manufactured in red, buff, black, chocolate and fawn. Because of their uniformity of shape these tiles provide a level surface, that is resistant to all but heavy wear, does not dust through abrasion, is easily cleaned with water and has a smooth, non-gloss finish which is reasonably non-slip when dry. They are used for kitchens, bathrooms and halls where durability and ease of cleaning are an advantage. Some common sizes are 300 × 300 × 15 mm thick, 150 × 150 × 12 mm thick and 100 × 100 × 9 mm thick.

Vitreous floor tiles
Vitreous tiles are made from clay and felspar, which gives the tile a semi-gloss finish. The tiles are uniform in shape and size and have a very smooth

semi-gloss or gloss surface that does not absorb water or other liquids and can be easily cleaned by mopping with water. Both vitreous and fully vitreous tiles may be moulded with a textured finish to provide a moderately non-slip surface. The gloss finish is impervious to most liquids, dust free and liable to be slippery, particularly when wet. Sizes are generally similar to those of plain colour tiles.

Laying clay floor tiles

The considerations that affect the choice of a method of laying floor tiles are:

❏ Tolerance: the fixing adhesive and tiles must be capable of accommodating any undulations and variations in the structure to which they fixed, so that the final tile finish is level
❏ Good adhesion to the base to provide solid support; this is particularly important for thin tiles if cracking of the tile is to be avoided
❏ Providing a means of accommodating relative structural, moisture and thermal movements between the base and the finish to prevent arching of the tile floor

Tiles are laid by the direct bedding method or the thin bed adhesive model.

Direct bedding method

The traditional method of laying tiles is to bed them on a layer of wet cement and sand spread over a screeded or level concrete floor with control joints at the manufacturer's recommended spacing.

Quarry tiles are laid and bedded in sharp sand and cement, 1:3 or 1:4 mix, spread to a level thickness of 15 to 20 mm, depending on the thickness of the tiles, on a fully dry concrete base. The cement and sand should be mixed with just sufficient water for workability and pressing the tiles into the bed. Too wet a mix will cause excess drying shrinkage. The main purpose of the bed is to accommodate the appreciable variations in thickness of the quarries to provide a reasonably level finish. The joints between the quarries will be up to 15 mm wide, to allow for variations in shape, and filled with cement and sand and finished level with the floor surface, or just below the surface, to emphasise the individual tiles.

The direct bedding method of laying is used for plain clay tiles on a bed some 10 mm thick and with joints between 5 and 10 mm wide, depending on variations in the size of the tiles and the need to adjust tile width to that of a whole number of tiles with joints to suit a particular floor size, thus avoiding the need to cut tiles on site.

Thin bed adhesive method

The majority of the thin, vitreous tiles that are used today are bedded and laid on an adhesive that is principally used as a bond between the tiles and the base,

and to a lesser extent as a bed to allow for small variations in tile thickness. The adhesives that are used are rubber latex cement, bitumen emulsion and sand and epoxy resins. These adhesives are spread on a level power floated concrete or a screed finish, to a thickness of from 3 to 5 mm, combed to assist bedding and the tiles are then pressed and levelled in position. Where the thin bed, epoxy resins are used as an adhesive for thin, vitreous tiles there should be no large protruding particles of aggregate or sand in the floor surface over which the brittle tile could crack under load.

Tiles arching – control joints

The word arching is the effect of tiles rising above their bed (the structural floor) in the form of a shallow arch. Arching is caused by expansion of the tiles relative to their bed or contraction of the bed relative to the tiles. With most finishing materials it is advisable to provide control joints, which allow the materials to shrink without causing unsightly cracks and expand without separating from their substrata.

Where there is a realistic likelihood of arching, the tiles may be laid on a bed spread over a separating layer so that movement of either the tiles or the base will not affect the floor finish. A layer of polythene film, bitumen felt or building paper is spread with 100 mm lapped joints over the concrete floor. The tiles are then laid and bedded on a cement/sand mix spread and levelled to a thickness of from 15 to 25 mm, depending on the thickness of the tiles, and jointed in the same way as for direct bedding.

Concrete tiles

Concrete tiles made of cement and sand, which is hydraulically pressed to shape as floor tiling, have been used as a substitute for quarry and plain colour clay tiles. The usual size of tiles is $300 \times 300 \times 25$ mm, $225 \times 225 \times 19$ mm and $150 \times 150 \times 16$ mm. The material may be pigmented or finished to expose aggregate. The density and resistance to wear depend on quality control during manufacture and the nature of the materials used. They are laid on a level power floated concrete or screed surface and jointed in the same way as quarries and plain colours.

Stone slabs

A wide range of natural stone slabs is used as a floor finish, from the very hard slabs of granite to the less dense soft marbles. Stone is selected principally for the decorative colour, variations in colour, grain and polished finish that is possible, and for durability. The method of bedding natural stone slabs as an internal floor finish varies with the thickness, size, nature and anticipated wear on the surface. Large, thick slabs of limestone, sandstone and slate up to 50 mm thick are laid on cement and sand with cement and sand joints. Thin slabs of granite and marble are laid by the thin bed adhesive method or the dry sand bed method, which is usually used for marble.

Joints

The width of the joints between tiles and slabs as an internal floor finish is determined by the uniformity of shape of the material used. For quarries, joints of up to 12 mm may be necessary to allow for the variations in size, and joints as little as 1 mm may be possible with very accurately cut and finished thin slabs of granite and marble. The disadvantage of wide joints is that the material used, such as cement and sand for quarries, will be more difficult to clean and will more readily stain than the floor material. Ideally, the jointing material should have roughly the same density, resistance to wear and ease of cleaning as the floor finish.

Control joints

The joints between tiles and slabs will serve the purpose of accommodating some movement of the floor finish. Some small expansion or contraction of the floor finish will be taken up in the joints through slight cracks or crushing of the very many joints.

In any large structure it is practice to form control (movement) joints to accommodate structural, moisture and thermal movement. These flexible joints should be continued through the rigid floor finishes as a flexible joint. Control joints should be formed around the perimeter of floors and against rigid abutments (e.g. columns) with an elastic sealant joint; it may also be necessary to divide rigid floor finishes into bays, separated by control joints. The disadvantages of these joints are that the joint material is necessarily softer than the surrounding surface, difficult to keep clean and will encourage wear of the edges of the finish next to the joint, thus careful consideration is needed when positioning control joints.

Timber floor finishes

Natural wood floor finishes such as boards, strips and blocks are used for the advantage of the variety of colour, grain and texture of this natural material, which is warm, resilient, and comparatively quiet underfoot.

Floorboards

Floorboards (described in Chapter 4) may be used as a floor surface to timber and to concrete floors. Either plain edge or tongued and grooved boards are used. The boards are nailed to wood battens set in a screed or to battens secured in floor clips. More usually, wood strip flooring is used.

Wood strip flooring

Strips of hardwood or softwood of good quality, specially selected so as to be particularly free of knots, are prepared in widths of 90 mm or less and 19, 21 or 28 mm in thickness. The type of wood chosen is one that is thought to have an attractive natural colour and decorative grain. The edges of the strip are cut
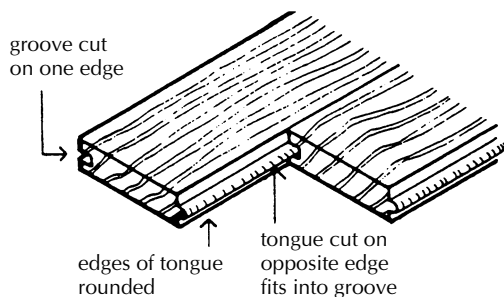
Figure 10.1   Tongue and groove strip flooring.

so that one edge is grooved and the other edge tongued, so that when they are put together the tongue on one fits tightly into the groove in its neighbour, as illustrated in Figure 10.1. The main purpose of the tongue and groove (T & G) is to interlock the strips so that its neighbours resist any twisting within an individual strip of timber.

There is always some tendency for wood strips to twist out of true, due to the wood drying out, and to resist this the strips have to be securely nailed to wood battens which are secured to the concrete floor, either by means of plugging and screwing the battens to the structural concrete, using mechanically fired concrete nails ('Hilti' nails, which penetrate both the timber batten and concrete), galvanised metal floor clips, or casting the batten in a cement and sand screed. The illustration of part of a concrete floor finished with wood strips nailed to battens is shown in Figure 10.2.

Wood strip flooring can also be fixed by the thin bed adhesive method. Comparatively short lengths of wood strip, 300 mm long, with tongued and grooved edges and joints, are used to minimise drying deformation. The strips are bedded on an epoxy resin adhesive spread over a true level screed on to which the strips are laid and pressed or rolled to make sound, adhesive contact. The strips are usually laid with staggered end joints. This is a perfectly satisfactory method of laying wood strip flooring as the narrow width and short length of strip is unlikely to suffer drying deformation which can tear strips away from the adhesive bed. Proprietary systems are also available that employ secret fixing methods, their cost and durability determined by the type of timber used and its quality.

Wood block floor finish
Blocks of wood are used as a floor finish where resistance to heavy wear is required, as in halls, corridors and schools, to provide a surface which is moderately resilient, warm and quiet underfoot. An advantage of the comparatively thick blocks is that after wear the top surface may be sanded to reduce the block to a level surface. The blocks are usually 229 to 305 mm long by 75 mm wide
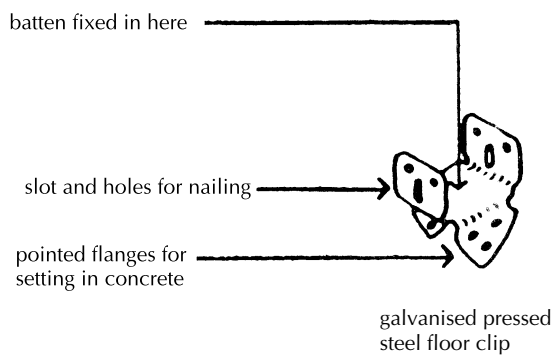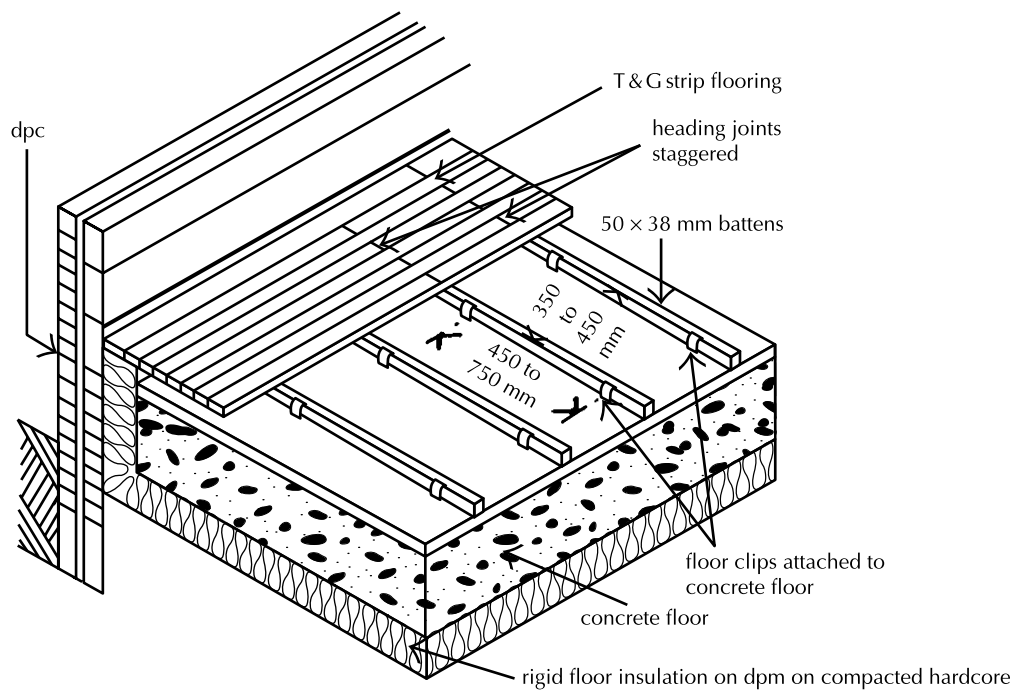
Figure 10.2   Strip flooring fixed to battens and clips.

by from 21 to 40 mm thick and are laid on the floor in a bonded, herringbone or basket weave pattern. The usual patterns are illustrated in Figure 10.3.

Wood blocks are laid on a thoroughly dry, clean, level cement and sand screeded surface, which has been finished with a wood float to leave its surface rough textured. The traditional method of laying blocks is to spread a thin layer

brick pattern   square basket   herringbone
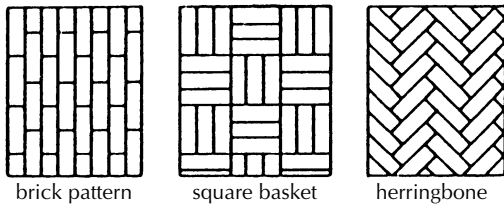
Figure 10.3   Wood blocks patterns.

of hot bitumen over the surface of the screed into which the blocks are pressed. The lower edges of the blocks of wood are usually cut with a half dovetail incision so that when the blocks are pressed into the bitumen some bitumen squeezes up and fills these dovetail cuts and so assists in binding the blocks to the bitumen, as illustrated in Figure 10.4. After the surface has been sanded to provide a level finish a wax polish or polyurethane seal is applied, to provide an easily cleaned finish.
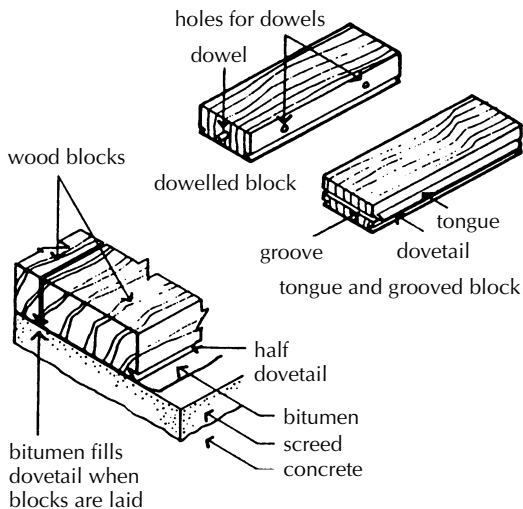
Figure 10.4   Joints for wood blocks.

10.3 Wall and ceiling finishes

Fairface finishes

Fairface brickwork, blockwork, etc.
Fairface brickwork or blockwork is used to describe the higher standard of finish (workmanship and quality of bricks or blocks) that is required to provide an aesthetically pleasing appearance. Particular attention is given to the joints;

the perpendicular joints should line up vertically and all of the mortar joints should be of a consistent thickness. A neat joint should be formed and drips and snots of mortar should not be allowed to come into contact with the face of the brickwork. A wide variety of rough, smooth and polished facing blocks and bricks are available. The type of brick or block selected will depend on the performance requirements, for example the performance requirements of fairface blockwork in industrial buildings, sports halls, showrooms, and large arenas (which may accommodate concerts) are quite different.

Internal plastering and dry lining

Plaster is the word used to describe the material that is spread (plastered) over irregular wall and ceiling surfaces to provide a smooth and level finish. The initially wet material is spread and levelled over uneven backgrounds such as brickwork, and over lath fixed to the underside of timber floor joists so that as it hardens and dries it forms a smooth, level wall and ceiling finish. The purpose of plaster is to provide a smooth, hard, level finish, which can be painted with emulsion paint, or to which wallpaper can be applied.

Airtightness and wet plaster and dry lining methods

Brick and block walls on their own are not particularly airtight. Gaps between horizontal joints, weep holes and unsealed cavities provide an interconnected passage of air from the inside to the outside of the dwelling. Wet plaster methods have been found to greatly improve the airtightness of masonry walls. Dry lining does not have the same effect. If the plaster board is applied using the dot and dab method, with plaster being spotted on the wall and the plaster board pressed against the wet plaster dabs, a gap is left between the back of the plaster board and the face of the wall. This gap then provides an additional air passage. Any gaps in the blockwork can then connect the cavity to the internal environment allowing air leakage. To increase airtightness when using plasterboard it is suggested that a ribbon of plaster (continuous strip of plaster) should be placed around the perimeter of each board (Figures 10.5A and B). Another method to increase airtightness is to coat the surface of the blockwork with a thin layer of rough plaster (2–3 mm) prior to applying the plasterboard (Figure 10.5 C).

Plaster undercoats and finish coat

The finished surface of plaster should be flat and fine textured (smooth). It would seem logical, therefore, to spread some fine grained material, such as lime or gypsum mixed with water, over the surface and trowel it smooth and level. The maximum thickness to which a wet, fine-grained material can be spread and levelled is about 3 mm. The irregularities in the surface of even the most accurately laid brick or blockwork are often more than 3 mm and it would be necessary to apply two coats to achieve a satisfactory finish. Instead

Continuous ribbon of
plaster prevents air
flowing between wall
and plasterboard

Plaster dabs

Plasterboard

Joints tapped and
sealed

Skirting board
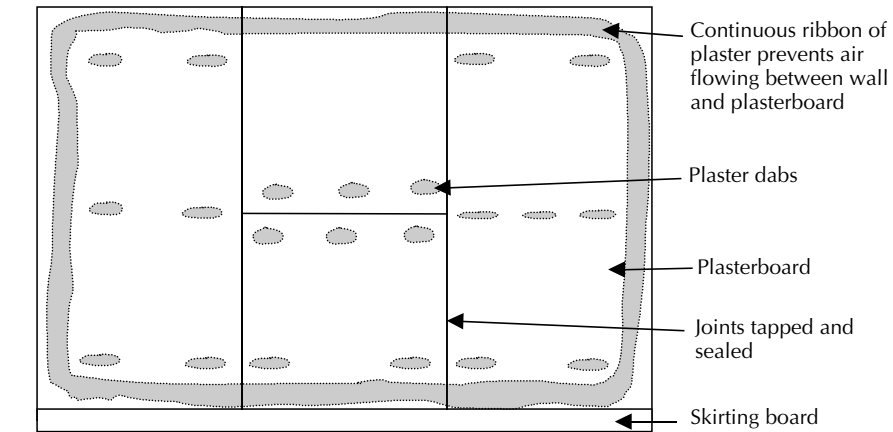
A   Elevation showing continuous ribbon running around perimeter of wall

Section through dry lined wall

Fixing adhesive runs
continuously around perimeter
of plasterboard to prevent
air movement

Edges of plaster board taped
and skimmed.

All mortar joints filled with mortar
to prevent air movement

Continuous plaster ribbon runs
along the bottom, top and sides
of plasterboard

Skirting board
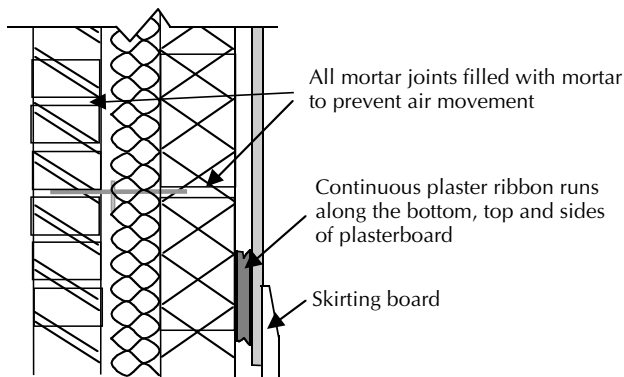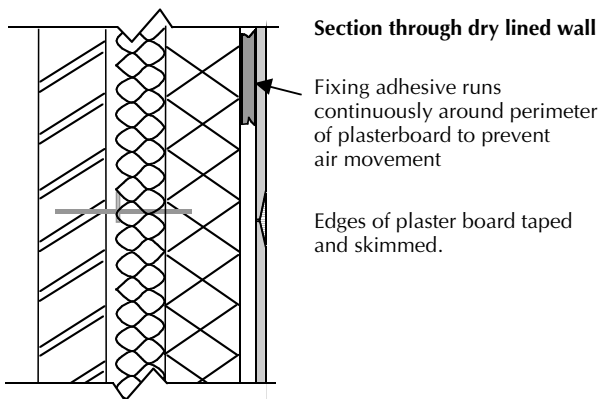
B   Section through dry lined wall with continuous ribbon

Figure 10.5   Sealing dry lined walls.

Section through dry lined wall

Fixing adhesive runs continuously around perimeter of plasterboard to prevent air movement

Edges of plaster board taped and skimmed.

Thin layer of plaster roughly applied to the surface of the blockwork. This helps to seal the porous blocks and any gaps in the blockwork joints. Sealing the blockwork prevents the gap behind the plaster board connecting with the cavity and allowing the passage of air.

All mortar joints filled with mortar to prevent air movement

Continuous ribbon runs along the bottom, top and sides of plasterboard

Skirting board

C   Section of dry lined wall with thin layer of plaster (pargin) roughly applied to seal surface of blockwork

Figure 10.5   (*continued*).

of applying a fine grained plaster in two coats it is common practice to spread some cheaper, coarse grained material that is easily spread as one or two coats to render the surface level and then finish this with a thin coat of fine grained plaster to provide a smooth finish. The coarse-grained coat or coats of plaster are termed undercoats and the fine grained final coat a finish or finishing coat.

Where some part of the surface of brick or block is particularly uneven it is practice to fill the hollows with undercoat plaster up to the general level of the wall face. This practice is termed 'dubbing out', ready for a two-coat plaster finish. One-coat plaster is gypsum plaster, which combines the qualities of both undercoat and finish plaster in one product. The material, which is spread and built up by hand to a thickness of 11 to 13 mm on brick and block backgrounds, is progressively trowelled to a reasonably level, smooth matt finish ready for decoration. The material, which is mainly used as a do-it-yourself (DIY) plaster, can be harder work to apply than a two-coat plaster.

Materials used in plaster

Lime plaster

Lime plaster is used in the restoration and preservation of older buildings. Lime is mixed with sand and water in the proportion of 1 of lime to 3 parts of sand by volume, with water for use as undercoat, and by itself mixed with water as a finish coat. As lime plaster dries and hardens it shrinks and fine hair cracks may appear on the surface. To restrain shrinkage and to reinforce the plaster, long animal hair is included in the wet undercoat mix, 5 kg of hair being used for every square metre of the lime undercoat (coarse stuff). The resulting haired, coarse stuff is plastic and dries out and hardens without appreciable shrinkage and cracking.

Cement plaster

Cement is mixed with sand and water for use as an undercoat for application to brick and block walls and partitions. It is used on strong backgrounds as 1 part of cement to 3 or 4 parts of clean, washed sand by volume. A wet mix of cement and clean sand (sharp sand) is not plastic and requires a deal of labour to spread. It is usual, therefore, to add a plasticiser to the wet mix to produce a material that is at once plastic and sets and hardens to form a hard surface. Usual mixes are 1 of cement, $\frac{1}{4}$ lime to 3 of sand, 1 of cement, 1 of lime to 6 of sand or a mix of 1 of cement to 4 of sand, with a mortar plasticiser by volume. As cement plaster dries out it shrinks fiercely and cracks may appear on the surface. In general the more cement used, the greater the shrinkage. The extent of the cracking that may appear depends on the strength of the surface to which the plaster is applied and the extent to which the plaster binds to the surface.

Gypsum plaster

The advantage of gypsum plasters is that they expand very slightly on setting and drying and are not, therefore, likely to cause cracking of surfaces. Gypsum is a chalk-like mineral, being a crystalline combination of calcium sulphate and water ($CaSO_4 2H_2O$). It is available as both natural gypsum, which is mined in areas all over the world, and as a synthetic by-product of major industries such as fossil fuelled power stations.

When powdered gypsum is heated to about 170°C it loses about three-quarters of its combined water and the result is described as hemihydrate gypsum plaster ($CaSO_4 \frac{1}{4} H_2O$). This material is better known as plaster of Paris. When gypsum is heated to a considerably higher temperature than 170°C it loses practically all its combined water and the result is anhydrous gypsum plaster. British Standard 1191 Parts 1 and 2 cover the manufacture of all traditional and modern gypsum based plasters. It is convenient to categorise gypsum plasters relative to their use as wall and ceiling plasters as casting, undercoat, finish, one coat and machine applied plasters.

Casting plaster

Finely ground hemihydrate gypsum (plaster of Paris) when mixed with water sets and hardens so quickly (about 10 minutes) that it is unsuitable for use as a wall or ceiling plaster. It is ideal for making plaster casts for buildings. Wet plaster of Paris is brushed into moulds to provide cornices and other decorative plasterwork. The wet plaster is usually reinforced with open weave hessian and is generally referred to as fibrous cast plaster or fibrous work.

Retarded hemihydrate gypsum plaster

The gypsum used for undercoats is retarded hemihydrate gypsum in which a retarding agent is added to plaster of Paris to delay the setting time for 1.5 to 2 hours to allow time for spreading and levelling the wet material as undercoat. For general use as an undercoat the retarded hemihydrate gypsum powder is mixed with lightweight aggregates, such as expanded perlite or vermiculite, as a dry mix powder, which is delivered to site in bags as pre-mix undercoat.

Pre-mix gypsum undercoat

The advantage of this material is that the pre-mix avoids the messy, wasteful operation of mixing dry powdered lime or cement with sand. The wet mix is comparatively easy to spread and level and the lightweight aggregate gives a small degree of thermal insulation. A disadvantage of the material is that the lightweight aggregate may not provide adequate resistance to damage by knocks. This material is applied as one undercoat to a finished thickness of 8 to 11 mm. In addition to the standard lightweight aggregate undercoat, other gypsum undercoat plasters are produced for specific backgrounds and also to suit specific performance criteria related to building use.

Bonding undercoat

Where the undercoat plaster is to be applied to a surface with particularly low suction, which does not readily absorb water, gypsum bonding undercoat is formulated to provide adequate adhesion.

High impact undercoat

In some situations where it is anticipated that rough or careless usage may damage standard undercoat plaster, high impact gypsum undercoat is used. A dense aggregate such as grains of silica are used in the pre-mix in lieu of the usual lightweight aggregate to provide improved resistance to knocks.

Finish plaster

Finish plaster is powdered, retarded hemihydrate gypsum by itself for use as a thin finish coat for both gypsum undercoats and to plasterboards. Mixed with water the plaster is spread and finished to a thickness of about 2 to 5 mm and sets in about 1 to 2 hours. This plaster, which is polished to a smooth surface, is also used as a finish to cement and sand undercoats.

Anhydrous gypsum plaster

Anhydrous gypsum plaster was commonly used as a thin finish coat to cement based undercoats. The powdered gypsum is mixed with a mineral sulphate to accelerate its set, which otherwise would be so slow as to make it unsuitable for use as a finish plaster. A characteristic of this gypsum plaster is that it can be brought back (retempered) by sprinkling the stiff surface to make it plastic for trowelling smooth, although this makes it unsuitable for use in damp or moist situations.

One coat gypsum plaster

One coat plasters are retarded hemihydrate plasters, which combine the properties of an undercoat and a finish coat. One coat is applied to a thickness of up to 20 mm as an undercoat. As the plaster begins to set (stiffen) it is sponged with water and trowelled to bring the fine particles to the surface so that it may have a finish comparable to that of a separate finish coat. Because of the considerable labour required to build up and level the surface, this plaster is not extensively used.

Machine applied gypsum plaster

Machine applied, or projection, plasters are one coat gypsum plasters designed to provide a longer setting time to allow for mixing, pumping, spreading and trowelling. The material is mixed with water, pumped and applied to the wall by a projection machine, which effectively halves the application time it would take to spread by hand. As the wet plaster covers the wall it is treated in the same way as one coat plaster by trowelling level and smooth. Because of the additional labour in mixing and pumping and the necessary work of cleaning equipment after use, this type of plaster may be most economically used on large flat areas of wall.

Background surfaces for plaster

The surface of walls to be plastered will affect the type of plaster used and its application. The surface of rough textured bricks and concrete blocks affords a 'key' for the mechanical adhesion of plaster to the background wall. As the wet plaster undercoat is spread and pressed into the surface, wet plaster fills the irregularities and as it hardens it forms a mechanical key to the background. With smooth faced bricks or blocks the mortar joints should be raked out some 12 mm, as the wall is built, to provide a key for the plaster. An advantage of the key is that it will restrain shrinkage of cement-based undercoats.

Suction

The word suction is used to describe the degree to which a surface will absorb water and so assist in the adhesion of plaster to a surface. Some lightweight concrete blocks readily absorb water and have high suction to the extent that

wet plaster applied to them may lose so much water that it is difficult to spread and may not fully set due to loss of water. Suction may be reduced by spraying the surface with water prior to plastering or by the use of a liquid primer. The most straightforward way of testing the suction of a surface is to spray it with water to judge the degree of absorption of water. There are liquid pre-treatments that can be applied to control the suction of surfaces.

PVA bonding agent

There are two main types of treatment to improve the adhesion of plaster to surfaces with low suction, such as concrete, to avoid the laborious process of hacking the surface to provide a key. The first is based on polyvinyl acetate (PVA) that is brushed or sprayed on to the surface. The plaster is applied before the PVA has fully dried and is still tacky; it is the tackiness that provides the bond.

Polymer bonding agent

The second pre-treatment is polymer based and incorporates silica sand. Once the polymer is fully dry the plaster is applied and gains bond through the silica grains and does not, therefore, depend on applying plaster as soon as the bonding agent is tacky. Where suction is high, as with lightweight blocks, the suction may be controlled by spraying with water or by spraying the surface with a liquid primer designed for the purpose.

Reinforcement for angles

A range of galvanised steel beads and stops is made for use with plaster and plasterboard as reinforcement to angles and stops at the junction of wall and ceiling plaster and plaster to other materials. An angle bead is pressed from steel strip to form reinforcement to angles. The bead has expanded metal wings, as shown in Figure 10.6. The wings of the bead are bedded in plaster dabs each side of the angle. The bead is then squared and plaster run up to it. A metal stop with an expanded metal wing is pressed from steel strip and used as a stop to make a neat finish at the junction of plaster with other materials at angles, skirtings and around doors and windows, as illustrated in Figure 10.6. The stop is either bedded in plaster or nailed to timber and the plaster is run up to the stop. These stops make a neat, positive break at junctions that would otherwise tend to crack or require some form of cover mould or bead to mask the joint. They are particularly useful at the junction of plaster to another material or where the plaster has to stop. Another bead or stop is designed for use at the junction of plaster and door and window frames to provide a definite break in surface between different materials, as illustrated in Figure 10.6. The stop is either bedded in plaster dabs or nailed to wood. The advantage of these beads is that they act as a break at the junction of dissimilar materials where they will mask any crack that may open. They are used instead of architraves.
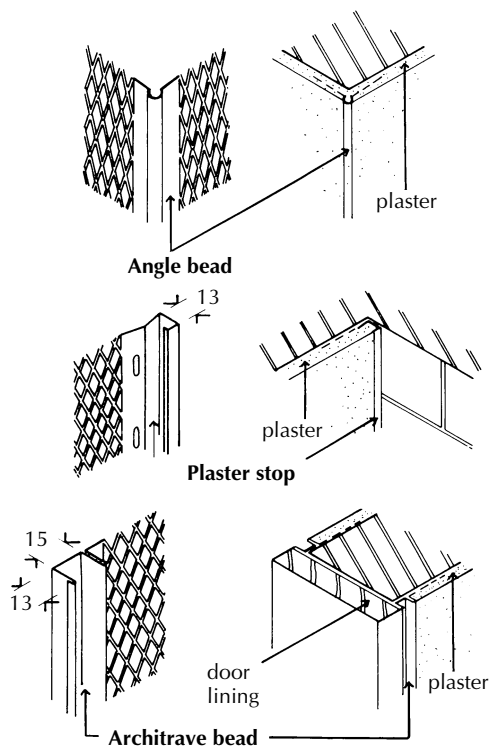
Figure 10.6   Metal beads and stops for plaster.

Plaster finishes to timber joists and studs

Timber lath
The original method of preparing timber ceilings and timber stud walls and partitions for plaster was to cover them with fir lath spaced about 7 to 10 mm apart to provide a key for the plaster. The usual size of each lath is 25 mm wide by 5 to 7 mm thick, in lengths of 900 mm. The softwood lath is either split or sawn from fir. Seasoned fir lath is nailed across the joists or timber studs. Obviously the ends of the laths must be fixed to a joist or stud, as illustrated in Figure 10.7, and the butt end joints of laths staggered to minimise the possibility of cracks in the plaster along the joints.

Fir lath is covered with three coats of plaster. The first coat is spread and forced between the laths so that it binds to it. This coat is described as pricking up. A second undercoat, termed the float coat, is spread and finished level and then covered with the finish or setting coat. Originally the undercoats consisted of haired coarse stuff (1 part lime to 3 parts sand, with hair) gauged with plaster of Paris, and the finishing coat of lime and water gauged with plaster of Paris. The purpose of the gauge (addition of a small amount) of plaster of Paris
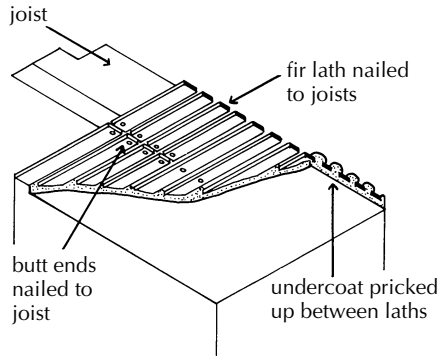
Figure 10.7   Fir lath and plaster.

is to cause the material to harden more quickly so that vibration due to the applications of the next coat, or vibrations of the floor above, will not cause the plaster to come away from the lath before it is hard. It is now used for specialist restoration work.

Metal lath (EML)

This lath is made by cutting thin sheets of steel so that they can be stretched into a diamond mesh of steel, as shown in Figure 10.8. This lath is described as EML (expanded metal lath). The thickness of the steel sheet, which is cut and expanded for plasterwork, is usually 0.675 mm and the lath is described by its shortway mesh. A mesh of 6 mm shortway is generally used for plaster. To prevent expanded steel lath rusting it is either coated with paint or galvanised. As a background for plaster on timber joists and studs, the lath, which is supplied in sheets of 2438 × 686 mm, is fixed by nailing with galvanised clout nails or galvanised staples at intervals of about 100 mm along each joist or stud. During fixing, the sheet of lath should be stretched tightly across the joists. Edges of adjacent sheets of the lath should be lapped by at least 25 mm.

EML can be used where the substrate to the plaster temporarily changes. For example, if a blockwall butts up to either side of a steel column and the plaster finish is required to cover the wall and the steel the EML can be used to provide a reinforced bridge as shown in Figure 10.9.
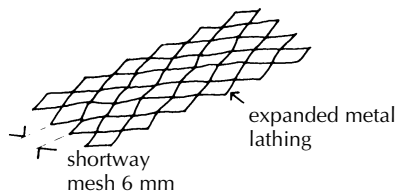
Figure 10.8   Expanded metal lathing.

Steel column

Expanded metal lath is fixed to the blockwork either side of the steel column and provides a reinforced bridge

Plaster, which is fixed to the blockwork and the lath, does not suffer the effects of differential movement between the steel column and blockwork

Expanded metal lath
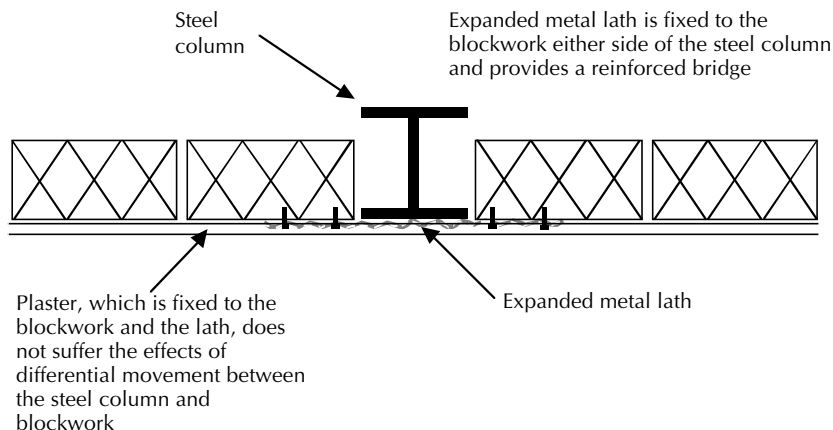
Figure 10.9   Plan view of Expanded Metal Lathing used to bridge different substrate.

Gypsum plasterboard

Gypsum plasterboard consists of a core of set (hard) gypsum plaster enclosed in, and bonded to, two sheets of heavy paper. The heavy paper protects and reinforces the gypsum plaster core, which otherwise would be too brittle to handle and fix without damage. Plasterboard is made in thickness of 9.5 mm, 12.5 mm, 15 mm and 19 mm, for use either as a dry lining or as a background for plaster in boards of various sizes. Plasterboard is extensively used as a lining on the soffit (ceiling) of timber floors and roofs and on timber stud partitions. The advantage of this material as a finish is that it provides a cheaper finish and can be fixed and plastered more speedily than lath and plaster. All gypsum plasterboards have inherently good fire resisting properties due to the incombustible core. The disadvantages are that, because it is a fairly rigid material, it may crack due to vibration or movement in the joists to which it is fixed, and it is a poor sound insulator (although special plasterboards with acoustic properties are now available). Many types of gypsum plasterboard are made for specific applications as dry linings.

Gypsum wallboard
Gypsum wallboard, which is the most commonly used board, is principally made for use as a dry lining wallboard to timber or metal stud frames with the joints between the boards filled ready for direct decoration. The boards have one ivory coloured surface for direct decoration and one grey face. The boards are 9.5, 12.5 and 15 mm thick, from 900 mm wide and up to 3600 mm long as illustrated in Figure 10.10. The length of the boards is chosen as a multiple of standard timber joist or stud spacings such as 400 or 450 mm to minimise wasteful cutting of boards. The boards are made with two different edges as
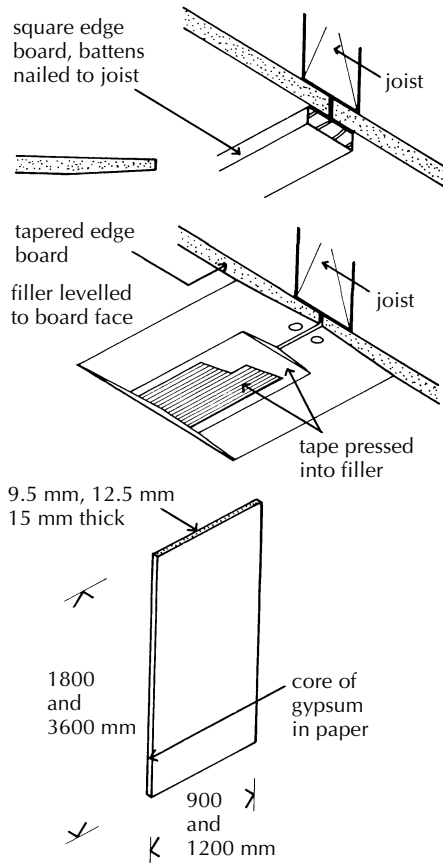
Figure 10.10   Gypsum wallboard.

illustrated in Figure 10.10, tapered for smooth seamless jointing and square for cover strip jointing.

Wallboard is fixed to timber or metal supports with its length at right angles to the line of joists or studs. Timber or metal noggins are fixed between supports to provide support and fixing for the ends of boards, which do not coincide with a support. Noggins are short lengths of timber, 50 × 50 mm in section, nailed between supports. The boards are fixed with galvanised nails, 30 mm long for 9.5 mm and 40 mm long for 12.5 mm thick boards, or self-tapping screws for metal studs. Nails and screws should be driven home to leave a shallow depression ready for spot fitting. Square edged boards are designed for use with a cover strip over all joints either for a panelled effect or for demountable partitions. Wood, metal or plastic strips are nailed or glued over joints. It is not uncommon for wallboard to be used as a base for a thin skim coat of gypsum plaster even though the smaller baseboard is more convenient

joist twists

joist deflects
(bends) and
plaster cracks
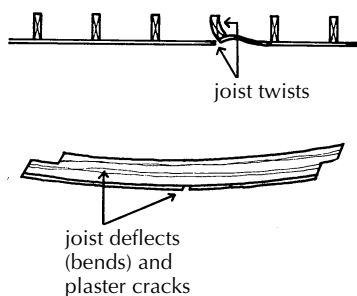
Figure 10.11   Cracking in plasterboard finishes.

to use, particularly to ceilings. Tapered edge boards are made for jointing with a smooth, flush finish ready for direct decoration. The shallow depression at the joint between boards is first filled with joint filler, made of gypsum and water, into which a 50 mm wide paper jointing tape is pressed. The joint is completed with filler, which is finished flush with the board as illustrated in Figure 10.10. Nail heads are covered with filler, finished smooth as spot filling.

The principal causes of cracking in these finishes are twisting and other moisture movements of timber joists or studs to which they are fixed and deflection of timber joists under load. New timber is often not as well seasoned as it should be and as the timbers dry out they tend to shrink and lose shape. Joists may wind (twist) and cause the rigid boards fixed to them to move and joints open up as illustrated in Figure 10.11. Strutting between joists will restrain movement and minimise cracking. Under the load of furniture and persons, timber floor joists bend slightly. The degree to which they bend is described as their deflection under load. Even with very small deflection under load a large rigid plasterboard will bend and cracks appear at joints as illustrated in Figure 10.11. One way of minimising cracking with large boards is to use joists some 50 mm deeper than they need be to carry the anticipated loads. This additional depth of joist reduces deflection under load and the possibility of cracking. Baseboard, made specifically for a plaster finish, is smaller than full size wallboard and may, therefore, be less liable to show cracks due to shrinkage and movement cracks.

Gypsum baseboard
Gypsum baseboard is designed specifically for use as a base for gypsum plaster. The board is 9.5 mm thick, 900 mm wide and 1220 mm long, and used as ceiling lining for their manageable size. The boards have square edges as illustrated in Figure 10.12. The boards are fixed with 30 mm nails at 150 mm centres with a gap of about 3 mm at joints. The joints are filled with filler into which reinforcing paper tape is pressed and the boards are covered with board finish gypsum
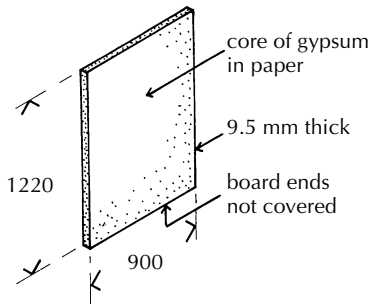
Figure 10.12   Gypsum baseboard.

plaster that is spread and trowelled smooth to a thickness of 2 to 5 mm as illustrated in Figure 10.13.

Gypsum plank
Gypsum plank is 19 mm thick, 600 mm wide and 2350 and 3000 mm long with either tapered edges for seamless jointing for direct decoration or square edges for plastering. This thicker board, which may be used for enhanced fire resistance or a small increase in sound insulation, may be fixed at 600 mm centres with 60 mm nails. For direct decoration the tapered edge boards are jointed and finished as described for wallboard. For plastering, the square edge boards are fixed with a gap of about 3 mm into which plaster or filler is run and reinforced with 50 mm wide paper tape. Gypsum finish plaster is then spread over the
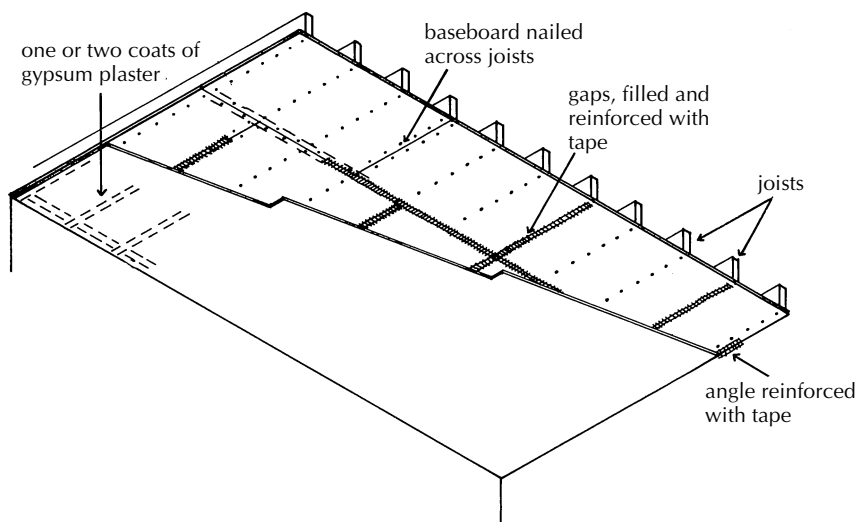
Figure 10.13   Fixing baseboard for plastering.
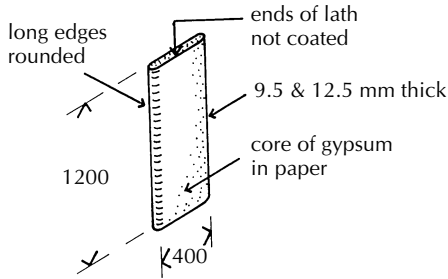
Figure 10.14   Gypsum lath.

surface of the boards, levelled and trowelled to a smooth finish to a thickness
of 2 to 5 mm.

Gypsum lath
These comparatively small boards are made specifically as a base for ceiling
lining for ease of holding and fixing and as a base for plaster either as a thin skim
coat or more particularly for a two coat finish. The two coat finish is preferred,
as the undercoat will facilitate accurate levelling over the many joints. Lath is
400 mm wide, 1200 mm long and 9.5 and 12.5 mm thick. The long edges of the
boards are rounded as illustrated in Figure 10.14. The lath is fixed to timber
joists and ceiling with a gap of not more than 3 mm between boards. The joints
do not have to be reinforced with tape. The lath is covered and finished with
one finish coat to a thickness of up to 5 mm or more, usually with a gypsum
undercoat 8 mm thick and a finish coat of about 2 mm thickness. The thicker
board with a two-coat gypsum plaster finish will provide improved resistance
to fire and some increase in sound insulation.

10.4 Skirtings and architraves

Skirting

A skirting (or skirting board) is a narrow band of material formed around the
base (skirt) of walls at the intersection of wall and floor. Usually the skirting
sits proud of the wall surface. It serves to emphasise the junction of vertical and
horizontal surfaces, wall and floor, and is made from material that is sufficiently
hard to withstand knocks. The skirting protects the wall finish at a vulnerable
point and also covers the joint between wall and floor. The materials commonly
used for skirting are timber, mdf, plastic, metal and tile.

Timber skirting board
Softwood boards, 19 or 25 mm thick, from 50 to 150 mm wide and rounded
or moulded on one edge are usually used. The skirting boards are nailed to

Typical timber skirting sections

rounded   splayed   moulded

50, 75 or 100   75 or 100   75, 100 or 150

19   19   19 or 25

plaster

skirting cut away to show plug

wood plugs driven into joints, skirting nailed to plugs

skirting mitred

skirting

plaster

timber ground nailed to brickwork for fixing skirting
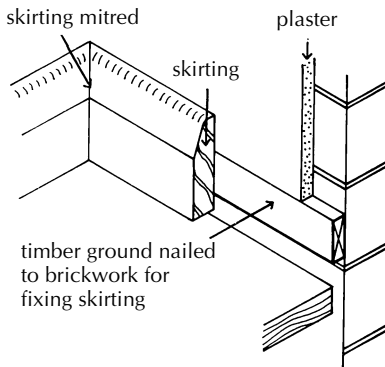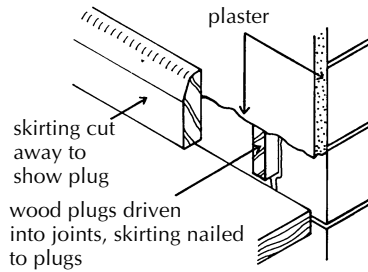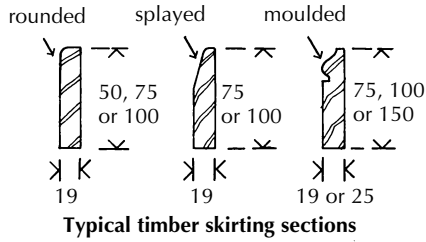
Figure 10.15   Fixing timber skirting.

plugs, grounds or concrete fixing blocks at the base of walls after plastering is completed. Figure 10.15 illustrates some typical sections of skirting board and the fixing of the board. Plugs are wedge-shaped pieces of timber that are driven into brick or block joints from which the mortar has been cut out as illustrated in Figure 10.15. This rough method of providing a fixing is usually unsatisfactory as it is not always possible to drive the wedge into a joint without damage and it is difficult to ensure that the face of the plug finishes at the required level. Nailing into the end grain of the wood plug may not provide a secure hold. An alternative is to nail soldiers to the wall. Soldiers are short offcuts of sawn soft-wood timber 38 or 50 mm wide and the same thickness as finished plaster. The soldiers are fixed vertically at intervals of 300 to 400 mm apart as a fixing

for the skirting board. Soldiers, which provide a more secure fixing than plugs, are laborious to fix.

Grounds are small section lengths of sawn softwood timber, 38 or 50 mm wide and as thick as the plaster on the wall. These timber grounds are nailed horizontally to the wall as a background to which the skirting can be nailed (as illustrated in Figure 10.15). Grounds are generally fixed before plastering is commenced so that the plaster can be finished down on to and level with them. Concrete fixing blocks are either purpose made or cut from lightweight concrete building blocks and built into brick walls at intervals of 300 to 400 mm as a fixing for skirtings. Another method of fixing wood skirtings is to run wall plasters down to floor level and fix the skirting with an adhesive directly to the plaster. The contact adhesive is spread on the back of the skirting and the plaster from a hand operated cartridge gun. These adhesives provide a secure bond to plaster. With long runs of skirting it is wise to supplement the adhesive bond with two or more screws, driven through the skirting into plugs in the wall, to resist shrinkage twisting of the wood skirting, which would otherwise pull the skirting from its adhesive fixing.

MDF
Medium Density Fibre board is increasingly used as a timber-based material into which grooves, rebates and complicated shapes can be cut. The material, which is made from fine particles of wood compressed and glued together, is less expensive than other timber boards, easy to work and finish and is more flexible than most natural wood boards. Where timber finishes are to be painted rather than varnished, mdf may offer an acceptable alternative to wood-based products in their more natural form.

Metal skirting
The traditional wood skirting was initially used to mask the joint between wall plaster and timber floor finishes where it was impossible to make a neat joint between lime plaster and boarded floors. The plasters used today are less liable to shrinkage and cracking and may be finished directly on to solid floor finishes or down on to pressed metal skirtings. A range of pressed steel skirtings is manufactured for fixing either before or after plastering. The skirting is pressed from mild steel strip and is supplied painted with one coat of red oxide priming paint. Figure 10.16 illustrates these sections and their use. The skirting is fixed by nailing it directly to lightweight blocks or to plugs in brick and block joints or to a timber ground. Special corner pieces to finish these skirtings at internal and external angles are supplied.

Tile skirting
The manufacturers of most floor tiles also make skirting to match the colour and size of their products. The skirting tiles have rounded top edges and a cove base to provide an easily cleaned rounded internal angle between skirting and floor. The skirting tiles are first thoroughly soaked in water and then bedded in sand

Type A for fixing before plaster

Type B for fixing after plastering
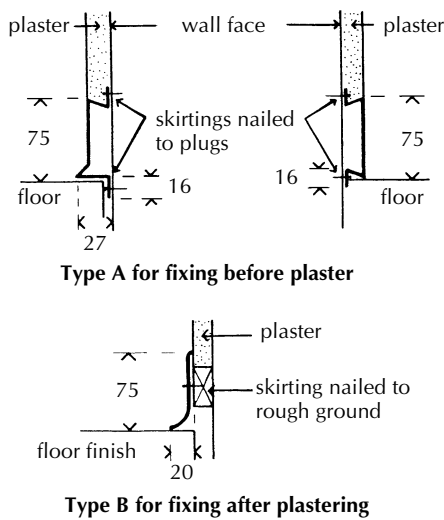
Figure 10.16   Metal skirtings.

and cement against walls and partitions as the floor finish is laid. Special internal and external angle fittings are also manufactured. Figure 10.17 illustrates the use of these skirting tiles. Skirting tiles make a particularly hardwearing, easily cleaned finish at the junction of floor and walls and are commonly used with quarry and clay tile finishes to solid floors in rooms and places where the conditions are wet and humid, such as kitchens, bathing areas and laundries. To avoid excessive condensation on smooth, hard surfaces such as tiles, they should be applied to floor and external walls surfaces that are adequately insulated.

Architrave

The word architrave describes a decorative moulding fixed or cut around doors and windows to emphasise and decorate the opening. An architrave can be cut or moulded on blocks of stone, concrete or clay, built around openings
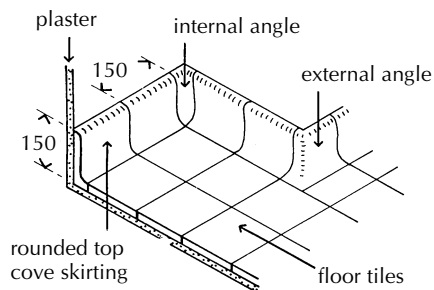
Figure 10.17   Tile skirting.

ex 25   ex 25

all are 50, 75 or 100 wide

Typical timber architraves

door frame

wall

plaster

architrave
nailed to
frame

skirting butts
to architrave

architrave nailed
to rough ground

door lining

architrave

plaster
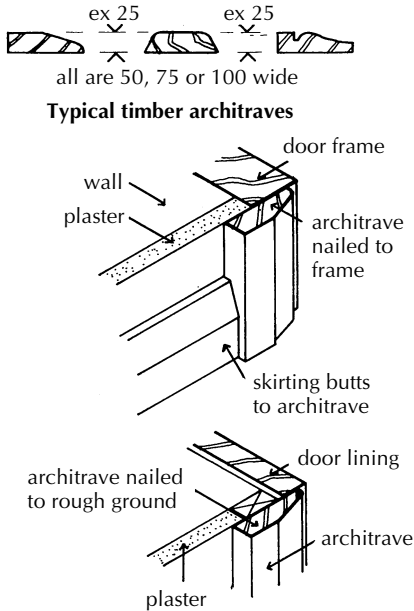
Figure 10.18   Architraves.

externally. Internal architraves usually consist of lengths of moulded wood nailed around doors and windows. An internal wood architrave serves two purposes: to emphasise the opening and to mask the junction of wall plaster and timber door or window frame. If an architrave is not used, an ugly crack tends to open up between the back of frames, linings and wall plaster. It is to hide this crack that the architrave is fixed.

A timber architrave is usually 19 or 25 mm thick and from 50 to 100 mm wide. It may be finished with rounded edges, or splayed into the door or decorated with some moulding. Usual practice is to fix architraves so that they diminish in section towards the door or window. Narrow architraves can be fixed by nailing them to the frame or lining of the door or window. Wide architraves are usually fixed to sawn soft wood grounds nailed to the wall around the frame or lining as a background to which the architrave can be securely nailed. Architraves are mitre cut (458 cut) at angles. Figure 10.18 illustrates some typical sections and fixing of architraves.

10.5 External rendering

Owing to their colour and texture, common bricks, concrete and clay blocks do not provide what is commonly considered to be an attractive external finish for buildings. The external faces of walls built with these materials are often

rendered with two or three coats of cement and lime mixed with natural aggregate and finished either smooth or textured. In exposed positions, walls may become so saturated by rain that water penetrates to their inside face. Because an external rendering generally improves the resistance of a wall to rain penetration, the walls of buildings on the coast and on high ground are often rendered externally to provide additional weather protection. External paints specially formulated for rendered surfaces may provide additional protection, while also helping to improve the appearance of the surface with the addition of some colour. In certain parts of the UK, render is the traditional finish to all buildings, old or new. Render is also used as a relatively cheap and convenient way of improving the weather resistance of old, less durable, walls.

Renders depend on a strong bond to the background wall, on the mix used in the rendering material and on the surface finish of the background. The rendering should have a strong bond or key to the background wall as a mechanical bond between the rendering and the wall and so that the bond resists the drying shrinkage inevitable in any wet applied mix of rendering. The surface of the background wall should provide a strong mechanical key for the rendering by the use of keyed flettons, raking out the mortar joints, hacking or scoring otherwise dense concrete surfaces and hacking smooth stone surfaces. If there is not a strong bond of rendering to background walls, the rendering may shrink, crack and come away from the background and water will enter the cracks and saturate the background from which it will not readily evaporate. As a general rule, the richer the mix of cement in the rendering material the stronger should be the background material and key.

The mixes for renderings depend on the background wall, lean mixes of cement and lime being used for soft porous materials and the richer cement and lime mixes for the more dense backgrounds so that the density and porosity of the rendering corresponds roughly to that of the background. The types of external rendering used are smooth (wood float finish), scraped finish, textured finish, pebbledash (drydash), roughcast (wet dash) and machine applied finish.

Types of render

Smooth or wood float finish

Smooth (wood float finish) rendering is usually applied in two coats. The first coat is spread by trowel and struck off level to a thickness of about 11 mm. The surface of the first coat is scratched before it dries to provide key for the next coat. The first coat should be allowed to dry out. The next coat is spread by trowel and finished smooth and level to a thickness of about 8 mm. The surface of smooth renderings should be finished with a wood float rather than a steel trowel. A steel trowel brings water and the finer particles of cement and lime to the surface, which, on drying out, shrink and cause surface cracks. A wood float (trowel) leaves the surface coarse textured and less liable to surface cracks. Three-coat rendering is used mostly in exposed positions to provide a

thick protective coating to walls. The two undercoats are spread, scratched for key and allowed to dry out to a thickness of about 10 mm for each coat; the third or finishing coat is spread and finished smooth to a thickness of from 6 to 10 mm.

Spatterdash

Smooth, dense wall surfaces such as dense brick and situ-cast concrete afford a poor key and little suction for renderings. Such surfaces can be prepared for rendering by the application of a spatterdash of wet cement and sand. A wet mix of cement and clean sand (mix 1:2, by volume) is thrown on to the surface and left to harden without being trowelled smooth. When dry it provides a surface suitable for the rendering, which is applied in the normal way.

Scraped-finish rendering

An undercoat and finish coat are spread as for a smooth finish and the finished level surface, when it has set, is scraped with a steel straight edge or saw blade to remove some 2 mm from the surface to produce a coarse textured finish.

Textured finish

The colour and texture of smooth rendering appear dull and unattractive to some people and they prefer a broken or textured surface. Textured rendering is usually applied in two coats. The first coat is spread and allowed to dry as previously described. The second coat is then spread by trowel and finished level. When this second coat is sufficiently hard, but still wet, its surface is textured with wood combs, brushes, sacking, wire mesh or old saw blades. A variety of effects can be obtained by varying the way in which the surface is textured. An advantage of textured rendering is that the surface scraping removes any scum of water, cement and lime that may have been brought to the surface by trowelling and which might otherwise have caused surface cracking.

Pebbledash (drydash) finish

This finish is produced by throwing dry pebbles, shingle or crushed stone on to, and lightly pressed into, the freshly applied finish coat of rendering, so that the pebbles adhere to the rendering but are mostly left exposed as a surface of pebbles. Pebbles of from 6 to 13 gauge are used. The undercoat and finish coat are of a mix suited to the background and are trowelled and finished level. The advantage of this finish is that the pebbledash masks any hair cracks that may open due to the drying shrinkage of the rendering.

Roughcast (wetdash) finish

A wet mix of rendering is thrown on to the matured undercoat by hand to a thickness of from 6 to 13 mm to produce a rough irregular textured finish. The gauge of the aggregate used in the wet mix determines the finish.

Machine applied finish

A wet mix of rendering is thrown on to a matured undercoat by machine to produce a regular coarse textured finish. The texture of the finish is determined by the gauge of the aggregate used in the final wetdash finish, which may have the natural colour of the materials or be coloured to produce what are called Tyrolean finishes.

11 Solid Fuel, Gas and Electrical Services Provision

The design of the services provision should be integral to the design of the building and its fabric, thus allowing greater ease of constructability on site and better access for routine repair and maintenance when the building is in use. Furthermore the EU directive on energy use of buildings is concerned with reducing the energy use of the overall building fabric, not just U values, thus helping to reinforce the need for an integrated approach.

11.1 Functional requirements

Heating, cooling, ventilation and electrical services provision enables the building to be used, i.e. function for its intended purpose. The quality of the internal space will be determined to a large extent by the type of heating, ventilation and services provision provided, which will in turn affect the wellbeing and comfort of the building's occupants. The main functional requirements are:

❑ Ease of use
❑ Energy efficiency
❑ Ease of maintenance and replacement
❑ Health and safety
❑ Comfort and wellbeing

11.2 Energy sources

Energy is either finite in supply or from renewable sources.

Finite fuels

The solid fuels available are bituminous coal (house coal), anthracite, smokeless fuels, coke, wood and peat. With the proliferation of central heating, these tend to be used for burning in fireplaces and stoves for additional radiant heat. There is an increasing trend to use fires and stoves as architectural features and a wide range of styles are available from which to choose.

Gas is primarily used for gas-fired boilers to work central heating systems and hot water supplies. Oil is an alternative in more remote areas that do not have gas mains in close proximity.

Electricity can be generated from finite materials, such as coal and gas, and also from renewable sources, such as hydro-electric and wind power as well as through solar collectors, such as photovoltaic cells.

Renewable sources of fuel

Primary renewable sources of energy are from the sun and from the wind.

Solar energy

Photovoltaic materials convert sunlight directly into electricity. Sunlight is a widely available resource and, although it varies with location, season and the time of day, photovoltaics can capture energy from the sun, even in climates such as that of the UK. PV cells produce direct current (d.c.) electricity that can be used immediately, transferred to the national grid or stored in batteries for later use (since the cells can only create electricity when the sun is shining). During their operation they give off no atmospheric or water pollutants; the only negative environmental impact is associated with the use of potentially toxic chemicals in their manufacture. PV cells are made of a semiconducting material, such as crystalline silicon, which convert up to 23% of sunlight into electricity. Alternative materials known as 'thin films' (e.g. gallium arsenide, copper indium diselenide and titanium dioxide) are also available and have potential as architectural features. Research and development is continuing to improve the efficiency of PV technologies and reduce the costs involved in their manufacture. Their use in buildings has considerable potential and can help in the drive to reduce carbon dioxide emissions. PV cells are incorporated into proprietary roof tiles, cladding panels and glazing.

Wind energy

Wind turbines are a proven method of generating electricity from a renewable source with minimal impact on the environment. Large wind farms are used to contribute electricity to the national grid, usually located in remote or sparsely populated areas. Smaller, local, wind farms are being introduced to supply renewable energy to urban and semi-urban areas (often as part of a larger regeneration initiative). The energy co-operatives are owned and run by local people, helping to improve social, economic and environmental quality. Concerns over visual impact and noise pollution have to be balanced against clean and sustainable sources of energy.

11.3 Solid fuel burning appliances

Open fire

The traditional open fire consists of a grate inset in a fireplace recess formed in a brick chimney breast, as illustrated in Figure 11.1. An open fire is clearly
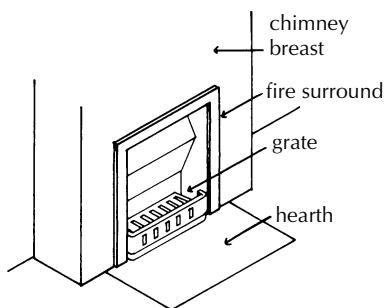
Figure 11.1   Open fire inset in recess.

visible and this is its chief attraction, usually provided as a means of additional or alternative warmth to a central heating system.

Formed at floor level on a solid hearth as part of a concrete floor or constructed in a timber floor, the fire will radiate much of its heat at floor level. So that an open fire will radiate heat more uniformly into the body of a room the fire may be raised above floor level as illustrated in Figure 11.2. A raised hearth of stone or concrete is built into the chimney breast to project from the face of the chimney to collect so much of the burning fuel as might otherwise fall on to the floor. As a safeguard a hearth is formed at floor level in timber floors to collect any burning material that falls from the upper hearth. As an alternative a grate may be set in a perforation in the upper hearth so that burning material and ash fall into a metal ash can set below the upper hearth. In larger living areas the fire may be built as a freestanding structure (Figure 11.3) or fitted where it is visible from one or more sides and where the heat generated by the fire will radiate from all four sides more generally to the living space.

An inset open fire is formed in a recess inside a chimney breast or wall under a flue built in the chimney breast. The fire is inset in a recess to contain the burning
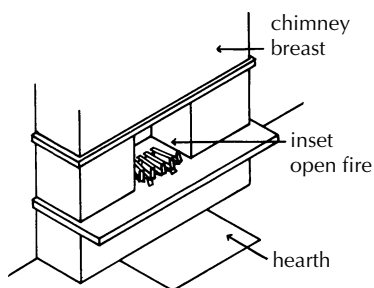
Figure 11.2   Open fire inset above floor in brick or block chimney breast.
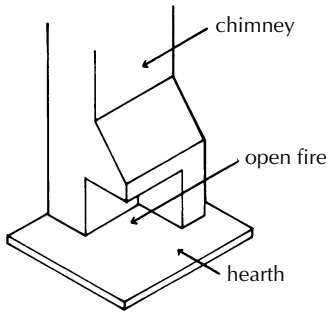
Figure 11.3   Freestanding open fire with brick or block chimney.

fuel and is open to transfer heat to the room by radiation and convection and for the benefit of a view of the fire. Inset open fires for the normal domestic room are generally for burning coal on an iron grate to contain the burning coals and provide some draught of air under and through the coals. The traditional grate is set in a fireback. Figure 11.4 is an illustration of a typical fireback, grate and fret. The fireback is made from fire clays, which are clays that contain a high proportion of sand with some alumina and can withstand considerable heat without damage. The fireback illustrated (in Figure 11.4) is a standard two-piece fireback for 350, 400 and 450 mm wide open inset fires. The fireback
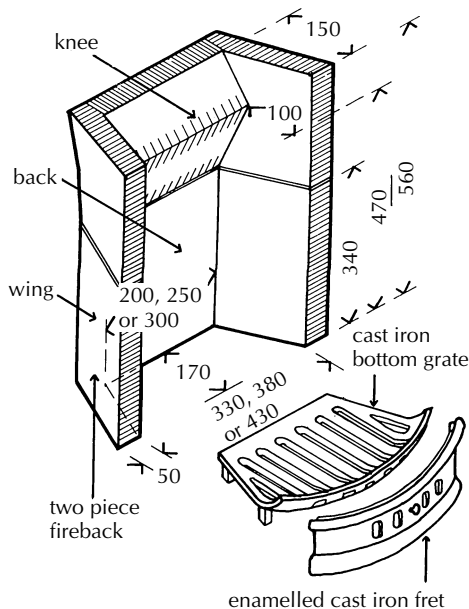
Figure 11.4   Fireback, grate and fret for open fire.
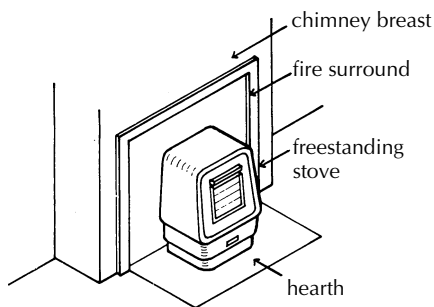
Figure 11.5   Freestanding stove (room heater).

may be in one, two, four or six pieces, the four and six piece backs being made to facilitate replacing an existing damaged fireback.

Room heaters

The room heater is a modern version of the traditional stove and is often provided as an additional source of heat to a central heating system. These often use wood as a fuel and form an architectural feature to new houses, with a wide range of styles and sizes available.

The advantages of the room heater are that air intake and combustion can be controlled to appreciably reduce the intake of excess air and so reduce the wasteful flow of heated air passing up the chimney. The whole of the surface area of a freestanding room heater is used to heat the room by radiation and convection of air around the heater. The room heater is set on a hearth in front of the chimney breast with a short length of flue pipe running from the back of the heater through a hole in the plate that seals the fireplace recess, as illustrated in Figure 11.5. These heaters may be set inside a fireplace recess or set as freestanding heaters inside the room, depending on the room available in front of the heater and its appearance. A hinged fuel door or panel in the front of the heater is glazed to give a view of the fire. The most efficient form of room heater is designed so that the primary combustion air intake is drawn down, through the bed of coal or timber in the grate, and then up to the flue as illustrated in Figure 11.6. For maximum efficiency, a down draught room heater is combined with a back boiler to take advantage of the heated combustion gases passing from the fire up the chimney. These back boilers are used to heat water and radiators.

Chimneys and flues

A flue is a shaft, usually vertical, to induce an adequate flow of combustion air to a fire and to remove the products of combustion to the outside air. The

air drawn
through coal

combustion
products rise
in flue

hot gases rise
around
water-ways

volatile matter
ignites in throat
between fire
bricks
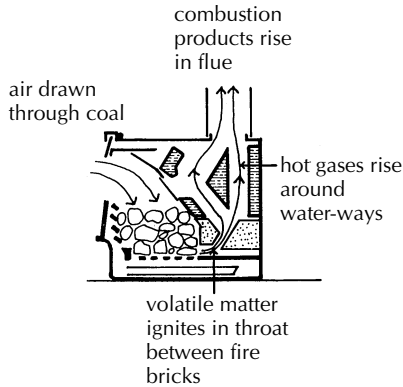
Figure 11.6   Down draught solid fuel burning heater.

material that encloses the flue, e.g. brick, block, stone or metal, is termed a chimney. A chimney may take the form of a pipe run to the outside or can be constructed of solid brick, block or stone, either freestanding or as part of the construction of a partition or wall (Figure 11.7).

Some of the heat of combustion of fires and stoves will be transferred to the chimney, which heats the structure and air surrounding it. To take the maximum advantage of this heat, the best position for a chimney is as a free-standing structure in the centre of a room or building where it is surrounded by inside air. As an alternative, the chimney may be built as part of an internal partition. Where buildings are constructed with a common separating or party wall, it is convenient to construct chimneys back to back on each side of the separating wall. Chimneys constructed as part of an external wall suffer the disadvantage that some of the heat will be lost to the outside, but can be minimised by continuing the cavity of an external wall and cavity insulation behind the chimney. The four positions for a chimney are illustrated in Figure 11.8.

It is usual to construct chimney breasts and chimneys as projections into rooms heated by open fires, with the chimney breast projecting into the ground floor room and the chimney projecting into the room above. The advantages of this arrangement are that the heated surfaces of the breast and chimney will transfer some heat to inside by radiation and convection and that the projecting breast will give some emphasis to the comparatively small fireplace openings. As an alternative, the chimney breast and chimney may be constructed to project from the face of the internal or external wall opposite to that of the fireplace recess, as illustrated in Figure 11.9. Whether the chimney and breast projection is inside or outside of an external wall it is necessary to continue the cavity and any necessary cavity insulation behind fireplace
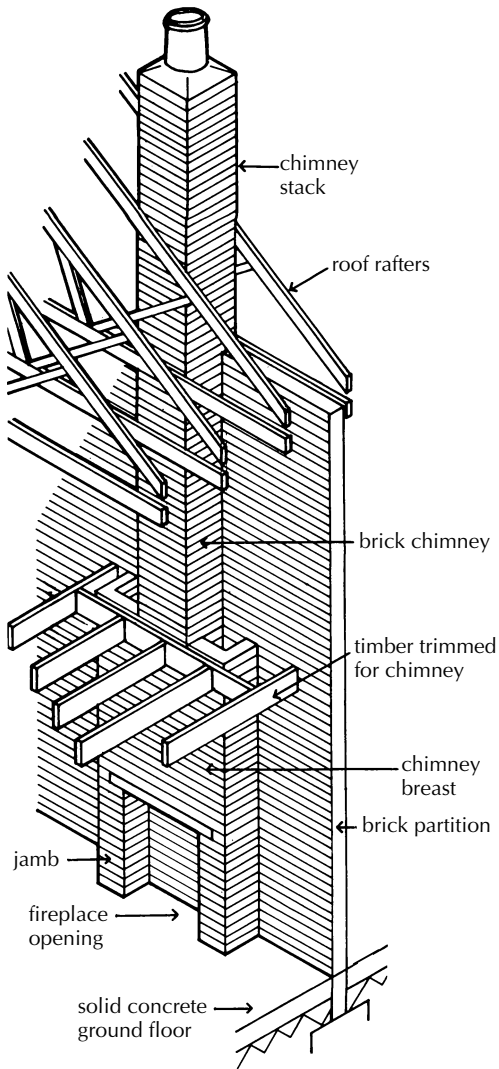
Figure 11.7   Brick chimney and chimney breast.

openings and flues. A fireplace or appliance recess is formed in the projecting chimney breast or wall into which the open fire or stove is set and above which the flue rises in the chimney breast. To support the brick or block work of the chimney breast over the fireplace opening, two piers are built either side of the recess. These piers, which are described as jambs (legs), support a brick arch or reinforced concrete lintel that supports the chimney breast. It is common to use a reinforced concrete raft lintel over the fireplace recess to

chimney stack

chimney breast

chimney

chimney stack

partition or division wall

Fireplace and chimney built with partition wall

chimney breast

Freestanding fireplace and chimney

chimney stack

chimney

chimney breast

separating wall

Fireplace and chimney built with party wall

chimney stack

chimney built with wall

Fireplace and chimney built with external wall

Figure 11.8   The four positions of fireplace and chimney.

support the chimney breast. The lintel is holed for the flue as illustrated in Figure 11.10.

Fire safety

Fireplace recesses

A requirement of the Building Regulations is that heat producing appliances be so installed and fireplaces and chimneys so constructed as to reduce to a reasonable level the risk of the building catching fire in consequence of their use. Approved Document J gives recommendations for the position and thickness of solid, non-combustible materials to be used in surrounds to open fireplaces and
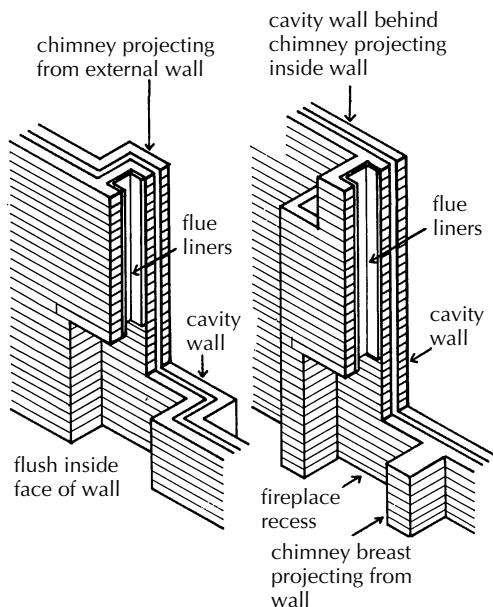
Figure 11.9   Fireplace and chimney in cavity wall.

the thickness and dimensions of solid, non-combustible materials in hearths under open fireplaces in, and in front of, open fireplace recesses.

The solid, non-combustible materials to enclose an open fire recess are brick, concrete block or concrete. The least thickness of these materials at the back of a fireplace recess should be at least 200 mm of solid walling or for each leaf of a cavity wall at least 100 mm and where a fireplace is built back to back at least 100 mm, as illustrated in Figure 11.11. In an external wall with no combustible cladding there should be at least 100 mm of solid backing.

The least width of the jambs, 200 mm, at the sides of a fireplace opening is indicated in Figure 11.10. This dimension applies whether the jambs project from a wall to support a projecting chimney breast or are part of the wall into which the recess is formed with the chimney breast or chimney projecting from the opposite side of the wall.

There should be an area of solid, non-combustible material in and projecting from fireplace recesses and under stoves, room heaters and other heat producing appliances. Where the floor under the fireplace recess and under heat producing appliances is at least a 125 mm thickness of solid concrete, the floor may be accepted as a hearth. The minimum area and thickness of solid, non-combustible hearths in and in front of fireplaces and freestanding hearths are illustrated in Figures 11.10 and 11.12.

Combustible material should not be used under a hearth unless it is to support the edges of a hearth or there is an air space of at least 50 mm between
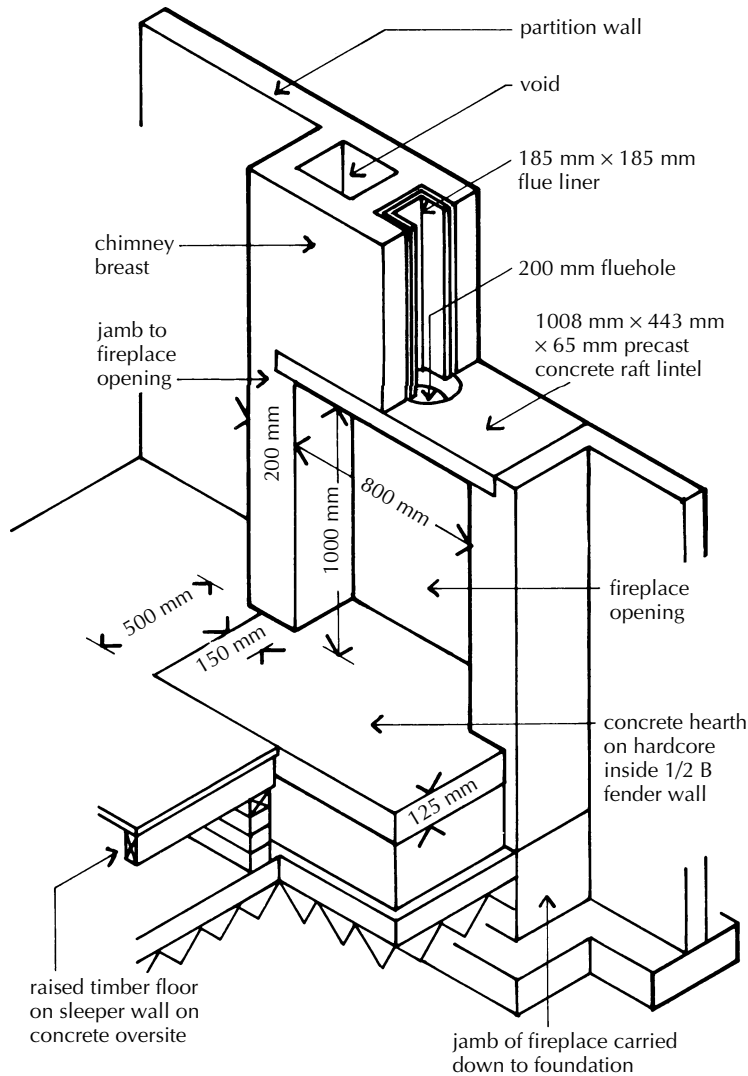
Figure 11.10   Fireplace, hearth and chimney.

the material and the underside of the hearth or there is a distance of at least 250 mm between the material and the top of the hearth. A freestanding hearth should extend at least 840 mm around the back and sides of an enclosed heat producing appliance.

A heat producing appliance should be separated from combustible materials by some solid non-combustible material 200 mm thick if the appliance is 50 mm or less from the non-combustible material, and 75 mm thick if it is between 50 and 150 mm from the non-combustible material. The non-combustible material should extend at least 300 mm above the top of the appliance.

solid wall at
least 200 mm
or a cavity
wall each leaf
100 mm thick

external wall,
the back to be
at least 100 mm

fireplace recesses
back to back not
less than 100 mm
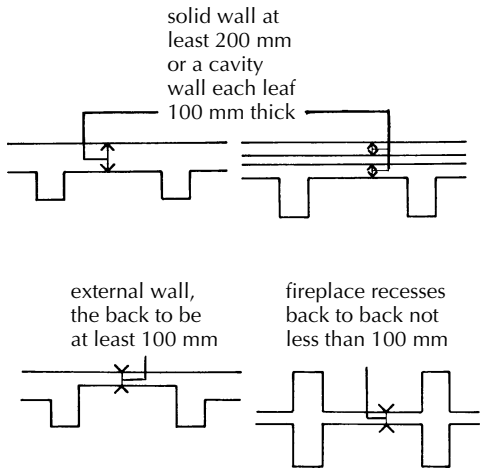
Figure 11.11   Thickness at back of fireplace recess.

Flues

A flue is a shaft or pipe above a fireplace to induce combustion air to flow and carry away the products of combustion. Approved Document J gives practical guidance to meeting the requirements of Part J of Schedule 1 to the Building Regulations for an adequate supply of air to fixed heat producing appliances for combustion and the efficient working of flue-pipes or chimneys.

Section 2 of the guidance, which applies to solid fuel burning appliances with a rated output up to 45 kW, requires a ventilation opening direct to external air of at least 50% of the appliance throat opening area, for open appliances, and at least 550 mm for each kilowatt of rated output.

The requirements for an air supply for combustion, like the requirements for room ventilation, are dictated by the trend over recent years to air sealed

Constructional hearth

150 mm
min

500 mm
min

150 mm
min

125 mm
min

840 mm
min

840 mm
min

125 mm
min

**Free standing
hearth**
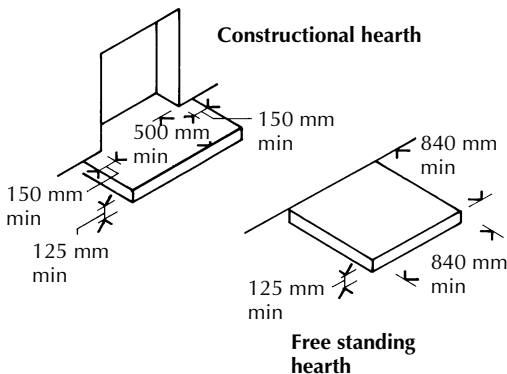
Figure 11.12   Constructional hearths.

Table 11.1   Size of flues

Installation	Minimum flue size
Fireplace recess up to 500 mm × 550 mm	200 mm diameter or square of equivalent area
Inglenook recess appliances	Free area 15% of area of the recess opening
Open fire	200 mm diameter or square of equivalent area
Closed appliance up to 20 kW output burning bituminous coal	150 mm diameter or square of equivalent area
Closed appliance up to 20 kW output	125 mm diameter or square of equivalent area
Closed appliance above 20 kW and up to 30 kW output	150 mm diameter or square of equivalent area
Closed appliance above 30 kW and up to 45 kW output	175 mm diameter or square of equivalent area

Source: Taken from Approved Document J, The Building Regulations 1991, HMSO.

windows and doors to contain heat and avoid draughts. The requirement for an adequate air supply for combustion must of necessity suppose a draught of cold outside air entering a room in which an open fire is burning vigorously, unless the fire or appliance is fitted with a separate air intake. The practical guidance in Approved Document J to the Building Regulations sets out the minimum flue size shown in Table 11.1.

For maximum efficiency the flue should be straight and vertical without offsets. As the heated products of combustion pass up the flue they cool and tend to condense on the surface of the flue in the form of small droplets. This condensate will combine with brick, block or stone work surrounding the flue to form water-soluble crystals which expand as they absorb water and may cause damage to the chimney and finishes such as plaster and paint. To protect the chimney from possible damage from the condensate, to encourage a free flow of air up the flue and to facilitate cleaning the flue, flue liners are built into flues.

Flue liners are made of burnt clay or concrete. Clay flue liners are round or square with rounded corners in section and have rebated ends (Figure 11.13). These liners are built in as the chimney is raised and supported on raft lintels over fireplace openings, and the liners are surrounded with mortar and set in place with the liner socket uppermost so that condensate cannot run down through the joint into the surrounding chimney. Bends are made of the same cross sections for use where flues offset. Concrete flue liners are made of high alumina cement and an aggregate of fired diatomaceous brick or pumice cast in round sections with rebated ends. Liners should be jointed with fire-proof mortar and spaces between the liners and the brickwork of flues should be filled with a weak mortar or insulating concrete.

To match the dimensions and bonding of concrete blocks, a range of purpose made precast concrete flue blocks is made for building into concrete walls as
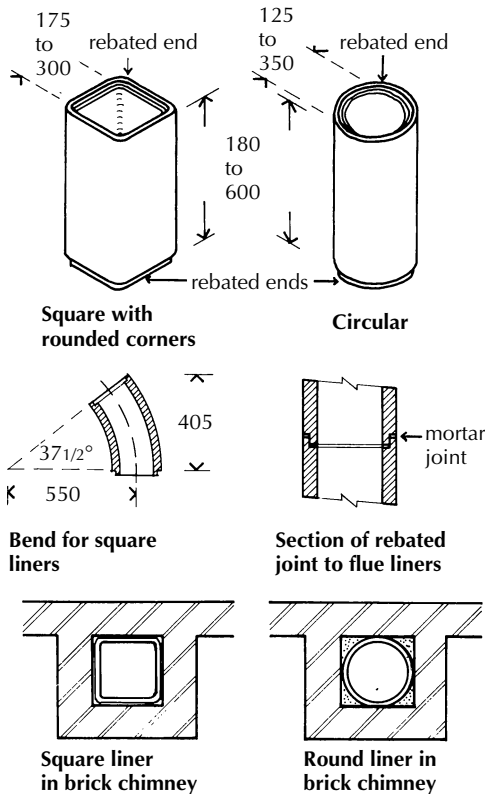
Figure 11.13   Clay flue liners.

flue and liner. Flue blocks are made of expanded clay aggregate concrete with a flue lining of high alumina cement and are rebated and socketed as illustrated in Figure 11.14. Both straight and offset blocks are produced to suit bends in the flue. At the junction of the chimney and the roof, a corbel block is used to provide support for the chimney blocks and the brick facing to the chimney above roof level. The brick facing is used as protection against rain penetration and for appearance sake. A precast concrete coping block caps the chimney and provides a bed for the flue terminal.

When gas burning open fires and gas fired appliances are connected to existing unlined brick built flues it is necessary to line the flue with flexible stainless steel liners that are drawn up the flue and connected to the appliance and a terminal.

Factory made insulated chimneys

These chimneys are designed to be freestanding inside buildings as a feature. Their advantages are their comparatively small cross section, ease of installation, high thermal insulation and smooth faces to encourage draught and
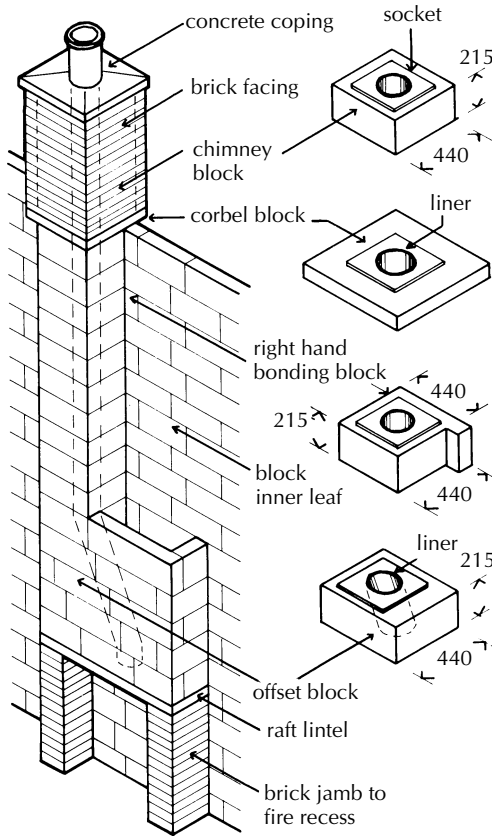
Figure 11.14   Precast concrete block chimney.

facilitate cleaning. Flue sections require some support at roof and intermediate floor levels, and have stainless steel inner linings and either stainless steel or galvanised steel outer linings around a core of mineral insulation that conserves heat and prevents condensation in the flue. Because of the insulation and construction of these flue sections, structural timbers may be as close as 50 mm to the outside of the flue, which avoids the need for trimming timbers and facilitates supporting the chimney at floor and roof level. The cylindrical flue sections are joined with socket and spigot ends that are locked together with a bayonet locking joint (Figure 11.15). Where the chimney passes through timber floor and roofs, metal fire stop plates that fit around the chimney are nailed to the underside and top of the joists around the flue and to timber dust stops nailed between the joists. Mineral wool fibre is packed around the flue sections and the joists and dust stops. At roof level a lead flashing dressed under the covering and around the flue fits into the spigot end of a weather sleeve section on to which a coping cap is fitted.
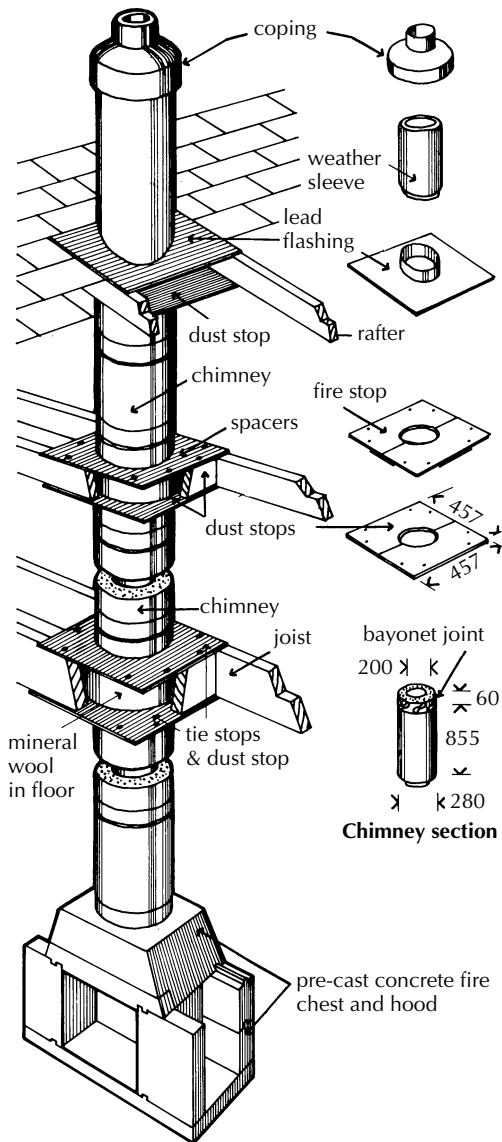
Figure 11.15   Factory built insulated chimney.

Proximity of combustible materials to chimneys

Combustible materials such as timber floor joists and timber rafters should be separated from flues in brick or blockwork chimneys and fireplace recesses to minimise the possibility of them becoming so hot as to catch fire. Approved Document J recommends that timber be at least 200 mm from a flue and 40 mm from the outer surface of a brick or blockwork chimney or fireplace recess unless
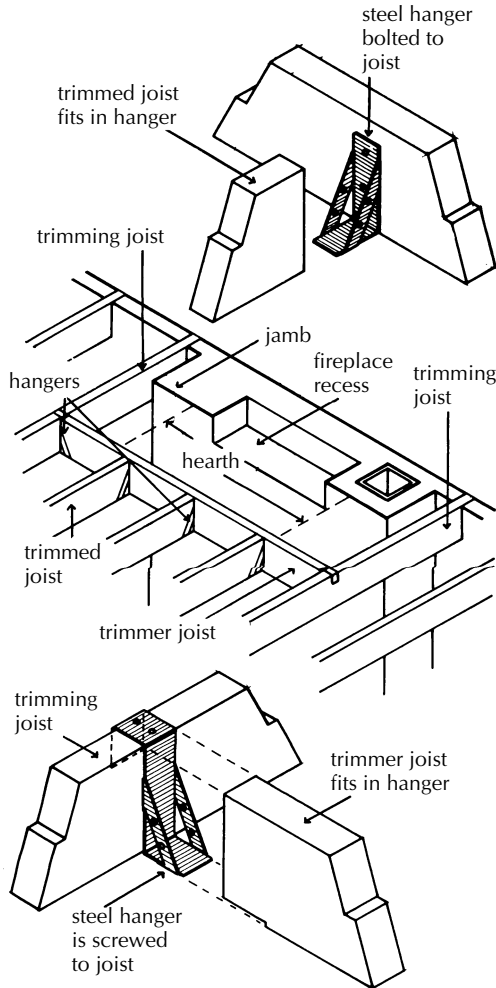
Figure 11.16   Trimming floor with metal hanger fixings.

it is a floorboard, skirting, dado or picture rail, mantelshelf or architrave. Metal fixings in contact with combustible materials should be at least 50 mm from a flue. So that no combustible material is closer than 200 mm from a flue it is necessary to build in the ends of trimming joists each side of the chimney breast as illustrated in Figure 11.16.

Floor construction around the hearth

The concrete hearth may be a precast concrete slab that is built into the walls surrounding the fireplace recess and supported by a steel shelf angle bolted to the trimmer joist or cast insitu on temporary boarding and supported by a shelf

angle bolted to the trimmer joist. Timber cradling pieces are fixed each side of the projecting hearth to provide support and fixing for the ends of floorboards running into the side of the hearth. These cradling pieces are supported on steel corbel plates built into the chimney breast and the trimmer. So that there is a strong, secure joint between the trimming, trimmer and trimmed floor joists pressed steel hangers are used (Figure 11.16). The ends of the joist are supported by steel hangers that are either hooked over or nailed and screwed to joists, as illustrated in Figure 11.16.

Chimney stacks above roof

Chimney stacks are raised above roofs to encourage the products of combustion to rise from the flue to the open air by avoiding down draught. The practical guidance in Advisory Document J to the Building Regulations sets minimum dimensions for the outlet of flues above roof level as illustrated in Figure 11.17. For roofs pitched at less than 10°, the outlet of any flue in a chimney or flue pipe should be at least 1 m above the highest point of contact between the chimney/flue pipe, and for roofs pitched at 10° or more, should be 2.3 m measured horizontally from the roof surface.

The outlet of any flue in a chimney or flue pipe should be at least 1 m above the top of any openable part of a window or skylight or any ventilator or similar opening which is in the roof or external wall and is not more than 2.3 m horizontally from the top of the chimney or flue pipe. The outlet of any flue in a chimney, or any flue pipe, should be at least 600 mm above the top of any
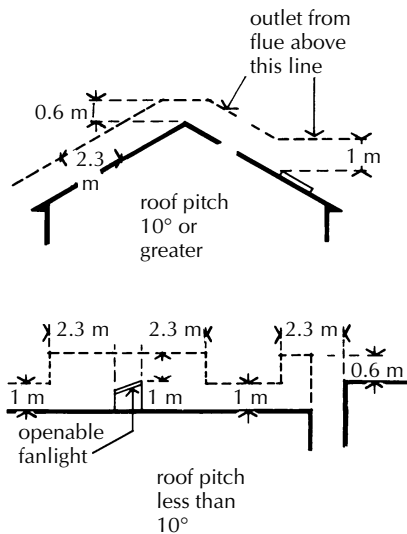
Figure 11.17   Outlets from flues.
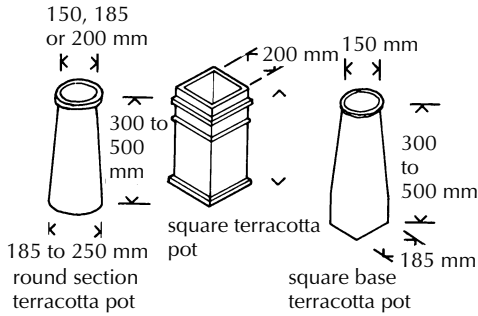
Figure 11.18   Flue terminals (chimney pots).

part of an adjoining building, which is not more than 2.3 m horizontally from the top of the chimney or flue pipe. For the sake of strength and stability, the practical guidance in Approved Document A sets the height of masonry chimneys at 4.5 times the least width of chimneys measured from the highest point of intersection of roof and chimney to the top of chimney pots or terminals.

Chimney pots, terminals
The traditional method of finishing the top of a brick chimney stack above the roof is with a chimney pot. The purpose of the chimney pot is to provide a smooth sided outlet to encourage the outflow of combustion gases to outside air and to provide a neat terminal to a stack which, with cement and sand flaunching around the pots, will provide resistance to weather. Some typical terracotta (burned earth) chimney pots are illustrated in Figure 11.18. The internal dimensions of these pots should be similar to that of the flue and the pots should be at least 150 mm high. The pots are bedded in cement and sand on the stack and flaunched around in coarse sand and cement and weathered to slope out as illustrated in Figure 11.19. A variety of chimney pots and galvanised steel terminals are produced with louvered sides, horizontal outlets and metal terminals designed to rotate with changes of wind direction to minimise down draught in flues.

Weathering around chimneys

At the junction of roof coverings and chimney stacks it is necessary to provide some form of weathering to prevent the penetration of rain into the roof; this is achieved by forming a system of flashings. The flashing should also be able to accommodate that differential movement between wooded roof and masonry stack. Where the pitched roof covering abuts the brick or stone chimney stacks it is weathered (sealed) by stepped lead flashings. Horizontal cuts, 25–35 mm deep, are made into the masonry joints. The inserts are positioned
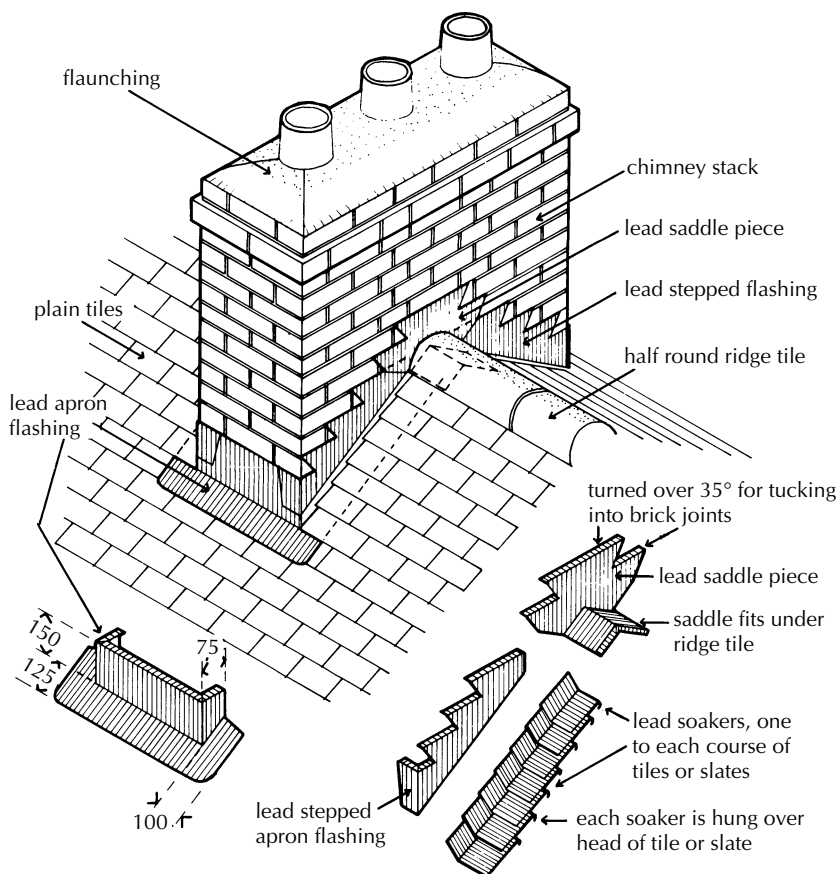
Figure 11.19   Lead flashings around chimney stack.

below the dpc so that any water from the dpc is cast to the outside of the wall and is carried away by the flashings. The flashings are inserted into the horizontal joints of the brickwork and dressed over the roof tiles, as illustrated in Figures 11.19 and 11.20. Soakers, which lap under the flashing and over the tiles, may be used where it is difficult to dress the flashings over the tiles. The stepped apron flashing overlaps the upstand of soakers by 50 mm and soakers overlap one another by the gauge of the roof covering. The edge of each step of the flashing is wedged into a raked out horizontal brick joint and pointed in mortar.

At the junction of the ridge of the roof and a stack a saddle piece is used and at the front of a stack, which is at right angles to the slope of the roof, a front apron flashing is used as illustrated in Figure 11.19. These flashings are tucked into horizontal brick joints, wedged and pointed. At the junction of side lap roof tiles and a chimney stack the stepped lead flashing is dressed down over
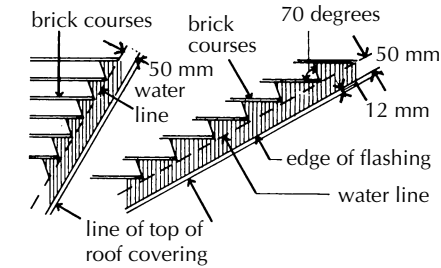
Setting out stepped apron flashing
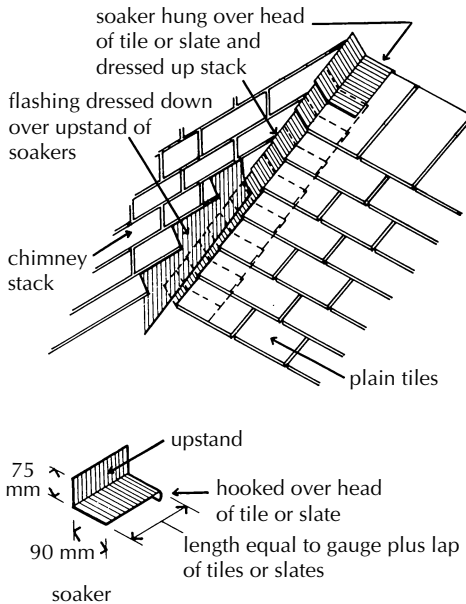
Figure 11.20   Stepped flashing and soakers.

the tiles to exclude rainwater as illustrated in Figure 11.21. Here there is no need for soakers, as the flashing dressed over the roll will suffice.

At the junction of a roof slope down towards a chimney stack it is necessary to form a lead back gutter to collect water running down the slope and divert it to run each side of the stack. The back gutter is shaped out of one sheet of lead to form an upstand, gutter bed and apron to dress under the roof covering as illustrated in Figure 11.21.

Lead is the metal, in sheet form, best suited to use as weatherings to stacks and roofs. It is used in thicknesses of number or code 5 or 4, which coincide with the old 5 lb and 4 lb weights of lead. The other metals in sheet form that may be used as weathering around chimney stacks are copper, aluminium
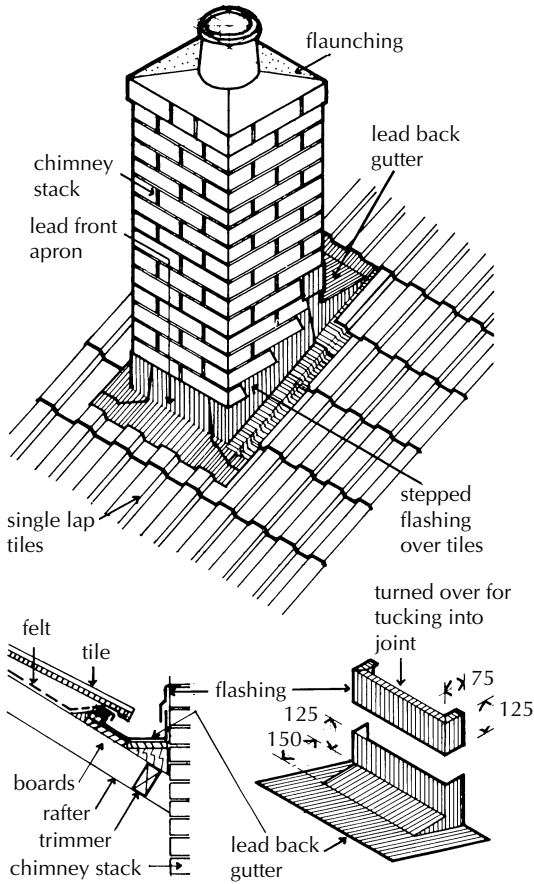
Figure 11.21   Single flue chimney stack through one slope of roof.

or zinc (see Figure 11.22). Copper, which is moderately malleable, suffers the disadvantage that it forms a blue oxide of copper in combination with water, which will be washed on to roof coverings to form an unsightly blue stain. Aluminium is moderately malleable and unlikely to cause stains. Zinc sheet is stiff and difficult to bend and shape, compared with other metals. Its low cost is outweighed by the difficulty in shaping the sheet.

11.4 Domestic gas installations

Natural gas, which is mainly methane, is supplied to UK consumers from the finite gas reserves in the North Sea. It is a high-grade controllable fuel, eminently suited to both domestic and commercial uses for heating. Natural gas is non-toxic and, as it is odourless, additives give warning of leaks by their distinctive smell.

apron folded from
one sheet of metal

three pieces of
copper, aluminium
or zinc welded or
soldered as back
gutter

two pieces of copper,
aluminium or zinc
welded or soldered
as saddlepiece

side pieces
welted to
frontispiece

single
welt

gusset

copper, aluminium or
zinc with gussets
welded or soldered
as front apron
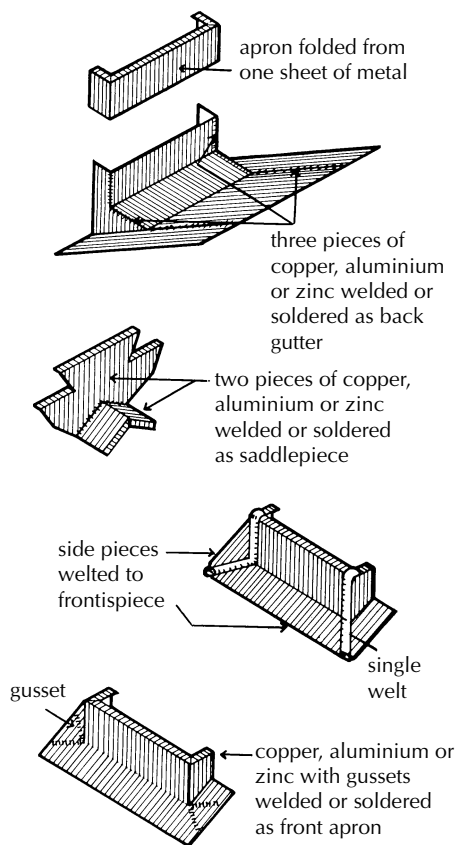
Figure 11.22   Non-ferrous metal flashings to chimney stack.

For the ignition and subsequent combustion of natural gas, a supply of oxygen and a gas temperature of about 700°C is necessary. In gas-fired cookers, fires and boilers the necessary oxygen is taken from an intake of air, which is drawn into the combustion chamber or zone, mixes with gas, is ignited and burns to complete combustion. The products of the complete combustion of gas are carbon dioxide and water vapour, which are expelled, either due to the pressure of combustion and the intake of air, to outside air by flues, or by convection. Where there is an insufficient intake of air to provide oxygen for the complete combustion of gas, the by-product will contain carbon monoxide, a gas that in very small quantities is lethal and can cause death in a few minutes. It is important, therefore, to ensure that all gas appliances are installed and serviced on a regular basis (annually) by an authorised CORGI registered person.

The design of gas burning appliances is concerned, primarily, to provide an optimum mix of gas (methane) and air for complete combustion for both efficiency in the use of fuel and the safety of occupants. It is essential that

convection currents for the intake of air and the evacuation of the by-products of combustion are designed in and maintained on a regular basis by a competent person.

Gas-fired boilers (combustion devices) are used, primarily, to heat water, which is then pumped around interconnecting pipework with radiators to give off heat; stop-valves and thermostats help to provide local control. Some warm air systems are also in use, with the air warmed by the boiler and driven around a duct system with fans. A detailed description of these systems is outside the scope of this book; however, it is important to know what type of system is going to be used early in the construction so that the building can be planned and subsequently constructed to enable economic pipe and duct runs. Boilers are generally described as 'conventional', 'condensing' or high-efficiency. To conserve energy, condensing boilers and high-efficiency boilers should be installed in preference to conventional boilers.

Gas supply

Gas is supplied under pressure through the gas main. A branch service pipe is run underground from the main to buildings. The service pipe is laid to fall towards the main so that any condensate runs back to the main, where it is collected. Where the consumption of gas is high, as in commercial and other large buildings, a valve is fitted to the service pipe just inside the boundary of the site to give the supplier control of the supply, for example in the case of fire. Domestic service pipes are run directly into the building without a valve at the boundary, and the meter valve or cock controls the supply.

The gas service pipe must not enter a building under the foundation of a wall or loadbearing partition, to avoid the possibility of damage to the pipe by settlement of the foundations. Gas service pipes running through walls and solid floors must pass through a sleeve so that settlement or movement does not damage the pipe. The sleeve is usually cut from a length of steel or plastic pipe larger than the service pipe, which is bedded in mastic to make a watertight joint.

Gas meter installation
The service pipe connects to the supply pipe through a gas meter installation which comprises a cock or valve governor, filter and a meter, for domestic premises, with the addition of a thermal cut-out and non-return valve for larger installations. Where possible, domestic meter installations are outside the premises in a position affording shelter, such as in a basement area under steps, or in a box or housing. The advantage of fitting the meter outside is that it is naturally ventilated and in a position where the meter reader can gain access when the occupier is out. Meter installations to large premises are often in a purpose-built meter house.
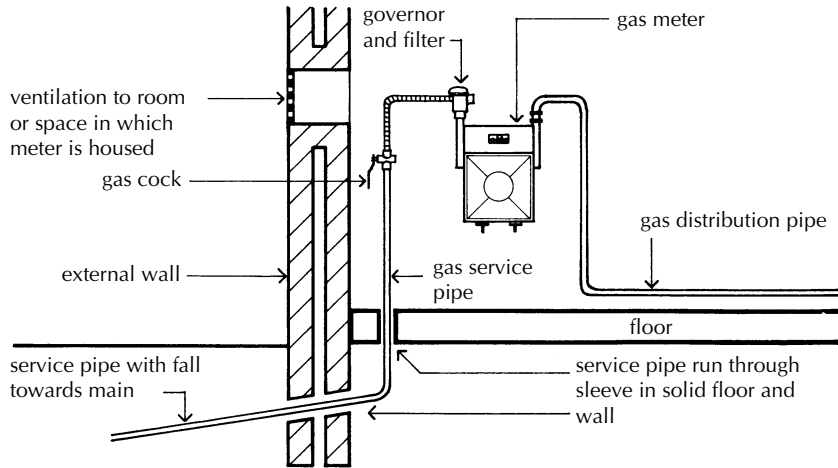
Figure 11.23   Gas supply.

Gas cock (valve)

A gas cock to control the supply from the service pipe to the governor and meter consists of a solid plug that in the shut position fills the bore of the cock, and in the open position only partly obstructs the flow of gas. A hand lever, as illustrated in Figure 11.23, operates the gas cock. The connection of the gas cock to the pressure governor is made with a short length of semi-rigid stainless steel tube that can accommodate any movement between the service pipe and meter, which might otherwise damage the meter.

Pressure governor and filter

For domestic installations a combined pressure governor and filter is fitted at the connection of the service pipe to the meter, as illustrated in Figure 11.23, and a separate governor and filter are used for larger installations. The fine mesh filter is fitted to collect pulverised particles of rust and metal that are carried along the main by the gas. The governor is a spring-loaded diaphragm valve, the function of which is to reduce the pressure of gas in the main to a pressure suited to gas burning appliances. The governor reduces mains gas pressure to 20 to 25 mbar standing pressure.

Gas meter and meter box

It is practice to fit gas meters in some position on an outside wall where there is access for meter reading. A metal meter box is fixed either on an external wall face or fitted to a recess in a wall to give some protection from weather. In this position the meter control cock or valve is more available for access in emergencies such as fire, than it is if it were indoors.

Pipework

The gas pipes, which are run from the meter to supply the various appliances, may be described as supply pipes. Commonly, the system of pipes is described as a gas carcass and the work of running the pipes as gas carcassing. Copper tubulars are used for most small gas installations. Capillary or compression fittings at connections are used in the same way that water pipework is run.

Pipe sizes

For safety, the size or bore of pipe used for gas carcassing should be adequate to deliver the necessary pressure of gas to each appliance. If the pipe is undersize, too low a pressure of gas at appliances may result in incomplete combustion and development of carbon monoxide, or there may be a flashback into pipework and an explosion may occur. The required size of pipe from the meter and the branches to each fitting, such as cooker, boiler and gas fire, depends on the volume and pressure necessary and the frictional resistance of the pipes and fittings to flow. The sizing of pipework can be made by a simple line isometric diagram (similar to that described for water pipe calculations).

Testing pipework

Newly installed gas carcassing must be tested for leaks, which is usually done after the gas burning appliances are connected and their supply shut off by closing gas cocks on each appliance. The pipework may be tested either before or after the meter has been installed. The procedure for testing after the meter has been installed is to turn off the main gas cock and all gas appliances and pilot lights. The screw of the test nipple, on the outlet of the meter, is removed and a pressure gauge or manometer is connected to the nipple. The main gas cock is slowly opened to let gas into the pipework until a standing pressure of 20 to 25 mbar is indicated on the manometer. The gas is turned off at the main cock and, after a wait of one minute, over the next two minutes the pressure indicated on the manometer should show no drop in pressure greater than 4 mbar, for domestic installations. If the pressure drops below the 4 mbar limit there is a leak, which can be indicated by leak detection liquid which, when sprayed around a leak, will bubble to indicate the position of the leak.

Purging is the operation of evacuating all air that has entered when the pipelines are first installed and when the gas is turned off for maintenance and repairs. The purpose of purging gas pipelines of air is to avoid the possibility of gas mixing with air in the pipelines, which could lead to an explosion. Air is purged by opening the main control cock and the cock to an appliance to cause the gas entering under pressure to force out all air. The gas is allowed to flow until there is a distinct smell of gas when the appliance or burner cock is closed. During this operation windows are opened and naked flames and electric sparks are avoided until the escaped gas is dispersed.

Flues to gas burning appliances

The by-product of the combustion of gas and air is heated gases that will rise by natural convection. The purpose of a flue or ventilation system is to encourage the heated gases to rise, by convection or by force of a fan to outside air.

Open flue appliances depend for their operation on an intake of air directly from the room, or enclosure, in which they are fixed, thus permanent ventilation to the outside air is essential. Manufacturers of gas appliances provide ventilation rates.

Natural convection flues depend for their operation on the natural draught or pull of heated gases rising from heating appliances. It is the function of flues to encourage heated gases to rise vertically from heating appliances to outside air. In general the higher a flue rises, the greater will be the draught or pull of hot gases.

Size of flue

There is an optimum size of flue to provide the best draught. The best cross sectional dimensions of a flue depend on the output from a heating appliance and the volume of air required for combustion of a particular appliance. Manufacturers provide detailed advice.

Existing flues

Where gas burning appliances are fitted in existing buildings it is common to use an existing open fire brick flue as the flue to the new appliance. The flue is first swept to clear loose, friable material and the draught up the flue is tested with a smoke-producing device. This will test for both the draught up the chimney flue and for an adequate intake of air by natural ventilation of air into the room. Where flues are built into an external brick or block wall it may be necessary to line the flue to minimise condensation of flue gases inside the flue, caused by too rapid a cooling of the rising gases. To provide the best section of unobstructed flue inside an existing brick or block chimney it may be necessary to line the flue with a flexible stainless steel liner which is pulled up the flue and sealed to a flue terminal and the gas appliance at the base. Flues built into new brick or block buildings are lined with clay pipes or purpose made flue blocks.

Flue pipes

The flue pipe to a heating appliance may be independent of, or secured to, a wall. Stainless steel, enamelled steel or aluminium are used for both single walled and double walled pipes. Double walled flue pipes consist of two concentric pipes separated by an insulating material. This insulating material maintains the heat and convection draught of flue gases and prevents the pipe, where it is exposed, becoming too hot.

Flue terminal

If a flue is to be effective in discharging flue gases to the open air it should rise above adjacent roofs and structures so that air currents blowing towards the flue terminal do not cause down draughts or suction currents as the blown wind gusts are deflected by surrounding buildings. A terminal is fixed to the top of the flue to deflect gusts of wind.

Room sealed appliances

Room sealed gas burning appliances are those that draw their combustion air intake directly from outside air instead of from inside air, as is the case with open flue appliances. The majority of small capacity boilers used for space and water heating for domestic premises such as flats and houses are specifically designed to be small and compact to fit into a kitchen or bathroom. These so called 'space-saving' boilers operate through a terminal fixed to the external face of a wall, into which air is drawn and from which combustion gases escape either by natural convection or fan assisted operation. With natural convection they rely on natural air movements and use a balanced flue to control intake and expulsion of gases. Alternatively, an electrically operated fan to assist extraction of combustion gases can be used. All these appliances are sealed so that no part of the intake air or exhaust gases enter the room in which the appliance is fixed. In operation both the balanced flue terminal and the smaller fan draught terminal will adequately disperse flue gases with extension to flues or flue pipes.

11.5 Domestic electrical supply and installations

Electricity is supplied to the majority of premises via the national grid. In isolated areas alternative forms of generation are required, e.g. oil fired generators. With continual innovations and improvements in the efficiency of wind and solar technologies it is now feasible and cost effective to generate electricity from alternative sources such as PV cells and local wind turbines. The electricity companies charge consumers on the units of electricity consumed.

Electrical circuits

To effect the transfer of energy from a source of potential electrical power, such as a generator or transformer, a complete circuit of some conductive material is necessary to provide a path of low resistance back to the source, so that the maximum energy is available around the circuit for conversion to lighting and heating and for motive power to rotary equipment. The material most often used as a conductor is metal in the form of a copper or aluminium wire.

With alternating current (a.c.) three phase supplies there are three separate conductors, one to each of the three separate phase windings of the generator
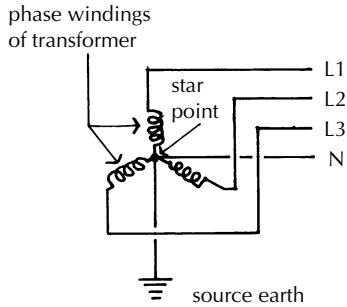
Figure 11.24   Phase conductors (L1, L2, L3) and neutral for TN-C-S supply. (See p. 586 for an explanation of TN-C-S.)

or voltage reduction transformer, and a fourth conductor serving as neutral back to the source to complete the circuit.

❑ Live: the three separate wires, which are termed phase or phase wires, are usually called live or live wires
❑ Neutral: the conductor that serves to complete the circuit is termed neutral
❑ Earth: this may be a separate conductor in some cables or, for economy, may be combined in other cables with the neutral conductor. Figure 11.24 shows the terms used. The earth conductor serves as a protective and safety device by acting as part of a conductive circuit with earth.

Electrical distribution

Consumer's installation

A consumer's electrical installation for small premises, such as a house, begins at the connection of the meter. From the meter a low voltage single phase, 240 V supply is run to the consumer's installation, which includes a consumer's unit and the necessary separate circuits for lighting, heating and power. A consumer's unit combines in one factory-made unit the necessary functions of a switch for isolation, circuit breaking devices (fuses) and distribution of supply to the various circuits.

Most modern units now also have an integral earth bar, which can accommodate all of the circuits' earths or circuit protective conductors (CPCs), the main earthing conductor and the main equipotential bonding conductors. Even with this arrangement, it is still convenient for testing to have a separate main earthing terminal connected to the consumer unit (Figure 11.25).

Earth system

The three distribution conductors housed in the consumer's unit are connected separately to the phase and neutral of the supply and to the earth conductor
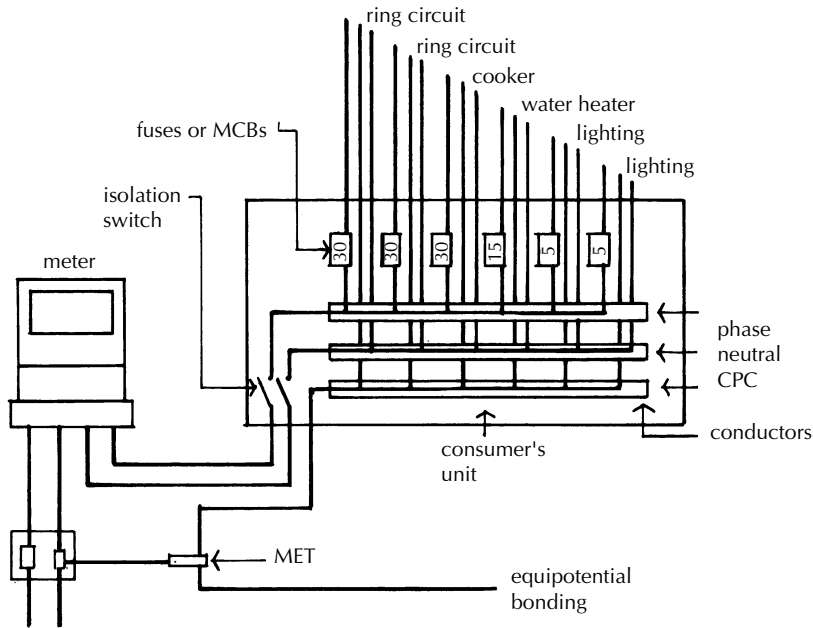
Figure 11.25 Connections to consumer's unit and circuit distribution.

made through the earth connection block. From the three distribution conductors the supply to each separate circuit is run from the phase conductor through an overcurrent protective device (fuse) and directly from the neutral and earth conductor to each circuit.

The UK electicity system is an earth system. This means that the star point or neutral point is connected to the general mass of earth, thus the star point is maintained at or about 0 V. Unfortunately this means that any persons or livestock that come into contact with a live wire and the earth are at risk of an electric shock (Figure 11.26).

People are at risk of electric shock by direct contact, i.e. touching live wires or parts of a system, or indirect contact, where a conductor, e.g. a metal casing, has become live due to a fault. The generally accepted effects of current passing through a human body are:

1–2 mA	Barely perceptible, no harmful effects
5–10 mA	Thrown off, quite a painful sensation
10–15mA	Body suffers muscular contraction, person shocked, can't let go
50 mA and above	Ventricular fibrillation and death

<div align="right">(Scaddan, 2003)</div>
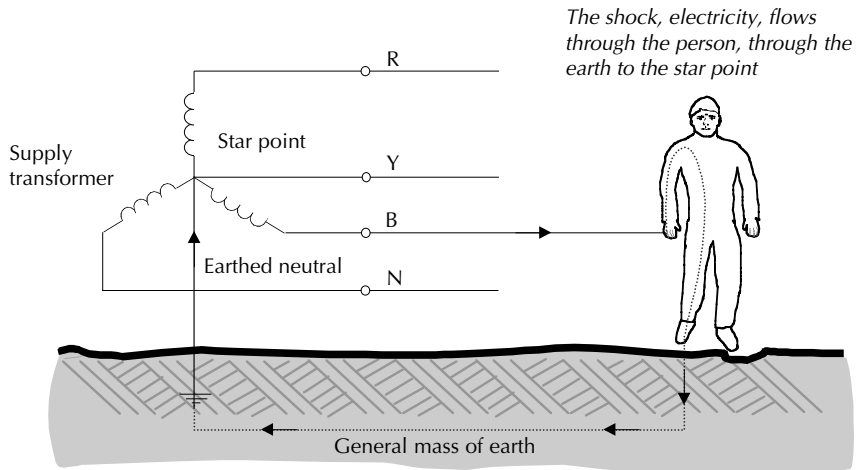
Figure 11.26   Risk of electric shock.

Protection against direct contact can be achieved by:

❏ Insulating any live wires or parts
❏ Ensuring that all live parts and systems are housed behind protective barriers or suitable enclosures

While residual current devices (RCDs) cannot prevent direct contact they can reduce the degree of exposure and possible effects. Residual current breakers (RCBs), residual current circuit breakers (RCCBs) and RCDs are terms for the same thing. Modern circuit breakers (CBs) now make it easy to protect individual circuits with a combined CB/RCD (RCBO). It should be noted that RCDs can malfunction and should not be the sole method of protection; however, they do provide effective back up.

The most common protection against indirect contact, through contact with live or extraneous conductive parts whilst touching earth is by earthed equipotential bonding and automatic disconnection of supply (EEBADS) (Scaddan, 2002b; 2003).

All of the extraneous conductive parts are joined together with a main equipotential bonding conductor, which is connected to the main earthing terminal, and all of the exposed conductive parts are connected to the main earthing terminal (MET) by the circuit protective conductors. This reduces the potential of electricity passing through a human body as the protective conductors provide an alternative path with less resistance. In addition to this, the overcurrent protection should operate fast enough when faults occur such that the risk of electric shock is significantly reduced.

Distribution and earthing systems

The IEE Regulations use the letters T N C and S as a classification system to identify the type of system used.

T = terre (French for earth); it indicates that there is a direct connection to earth.
N = neutral
C = combined
S = separate

When the letters are grouped together the following system applies.

First letter.   The first letter identifies how the supply is earthed.

T = at least one point of the supply is directly connected to the earth

Second letter.   The second letter shows the earthing arrangement, how the metalwork of an installation is earthed.

T = all exposed conductive metalwork is directly earthed
N = all exposed conductive metal work is connected to an earth, which is
    provided by the supply company

Third and fourth letters.   The third and fourth letters indicate the function of neutral and protective conductors.

S = the earth and neutral conductors are separate
C = the earth and neutral conductors are combined

Common supply and earthing arrangements are (Figure 11.27):

TT   Mostly used in rural areas where the supply is overhead. An example is an overhead supply with earth electrodes, and the mass of earth as a return path. The system has a direct connection of the supply source to earth and a direct connection of the installation metalwork to earth.

TN-S   This type of arrangement is used widely in the UK. The supply company provides an earth terminal with the intake cable. Normally the supply cable has a metal (lead) sheath around the cable (supply protective conductor), which connects back to the star point at the area transformer, where it is earthed. Thus, the system has the supply source directly connected to the earth. The installation metalwork, which is connected via the lead sheath of the supply cable and the neutral and protective conductors, performs separate functions throughout the whole system.

TN-C-S   In this earthing system the supply cable sheath forms the combined function of earth and neutral conductor; this is known as PEN (protective earth neutral). At the consumer's installation it changes to the TN-C-S system. The earth and neutral are separate. This is also known as a protective multiple earthing (PME).
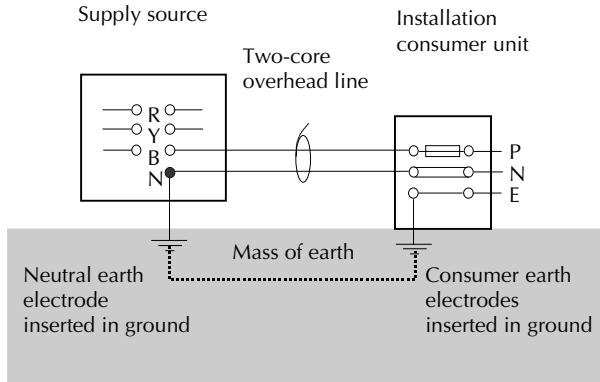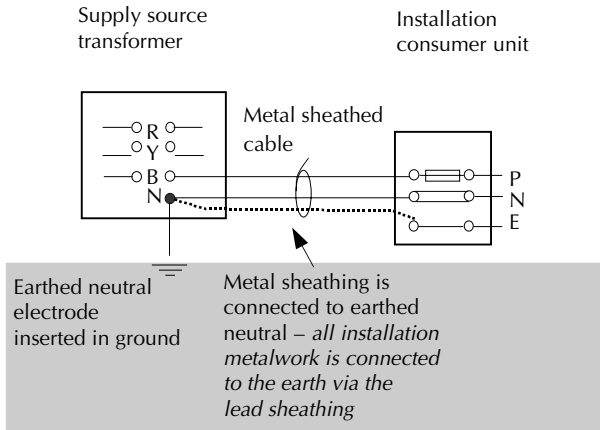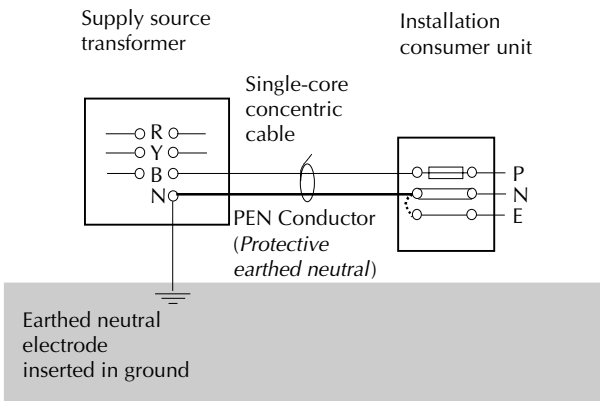
Figure 11.27   Earthing systems.

Main intake in domestic installations

Unless the domestic premises are large it is unlikely that a three phase supply would be needed. Single phase systems are generally adequate for domestic properties.

Many TT systems have been installed and protected by a single 30 mA residual current device (RCD); this does not conform to the current IEE Regulations. Under the regulations each circuits that needs to be controlled separately (lighting and power) should be able to remain in operation in the event that the other circuit fails. A failure on a socket outlet should not cause the lights to be cut off.

An installation can be protected by a 100 mA RCD and using a split-load consumer unit; the socket outlet should be protected with a 30 mA RCD. However, modern RCBOs, which combine RCD/MCD (residual current devices/miniature circuit breakers), make the use of 'split-load' boards unnecessary. Where socket outlets are intended for connection to portable appliances for external use, such as lawn mowers, a 30 mA RCD is required to protect the circuit.

Main earthing terminal (MET) and integral earth bars

To provide a means of connecting the earthing conductor of the TN-C-S supply cable to the means of earthing for the consumer's installation and to the main equipotential bonding, a main earthing terminal (MET) is included as part of the consumer's installation. The MET is made as two blocks of metal with a disconnectable link, as illustrated in Figure 11.28. The disconnectable link is provided as a means of testing.
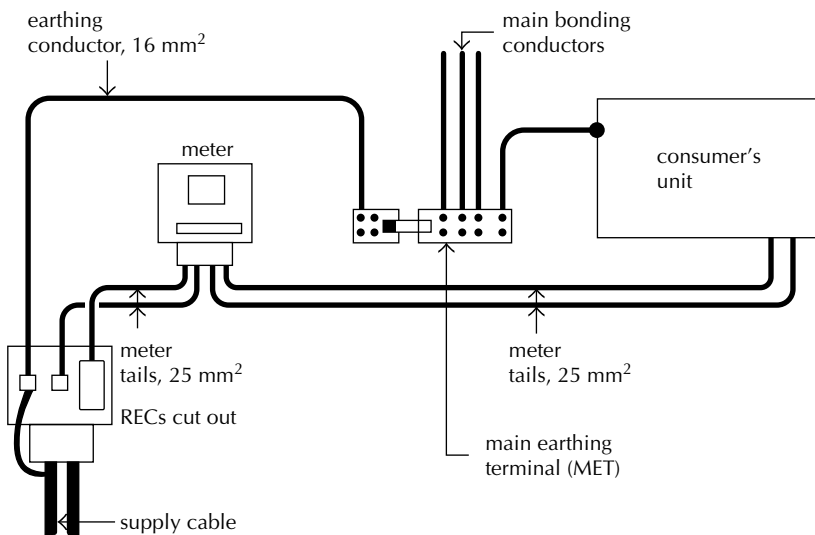
Figure 11.28   Supply connections for a TN-C-S system.

A conductor is run from the supplier's common earth and neutral conductor to the smaller MET block, and a conductor is run from the main MET block to the earth distribution in the consumer's unit. This provides the necessary earth connection to the various circuit protective conductors (CPCs) to protect the installation against damage and danger of fire or shock to persons. Where there is a failure of insulation to a live conductor, and contact between the conductor and a conductive part of the installation, the CPC provides an alternative path of least resistance for unpredicted currents to flow to earth. One or more earth conductors are run from the main MET block to the extraneous conductors, such as metal water, gas, oil and heating pipes, as main equipotential bonding. The conductors connect the gas and water services together, and maintain such services within the premises at or about earth potential (about 0 V). It must be remembered that bonding the installation earthing to gas, water and oil services is not done to gain an earth – many services are now made from non-metallic materials.

Most modern units have an integral earth bar, which can accommodate all of the circuit's earths or CPCs, the main earthing conductor and the main equipotential bonding conductors. Even with this arrangement, it is still convenient to have a separate main earthing terminal, which is connected to the earthing conductor from the consumer unit. Such an arrangement is useful for installation testing.

Main isolation

Normally the consumer unit has a single switch that provides the means to isolate the whole supply. There is a requirement that isolation switches should be accessible at all times. They should not be positioned in storage cupboards where they are likely to become obstructed. Unfortunately this is often overlooked as consumer units are hidden from general view, more often than not in service cupboards.

Overcurrent protective devices

In the phase (live) conductor to each circuit cable run from the distribution conductor, is a fuse or circuit breaker as protection against a current greater than that which the circuit can tolerate. The purpose of these devices is to cause a break in a circuit as protection against damage to conductors and insulation by overheating caused by excessive currents.

The main priority of a fuse or MCB is to protect the circuit conductor, not the appliances or user. It is therefore essential that calculation of cable size involves the correct selection of protective device (Scaddan, 2003). The are many types of fuses and circuit breakers; however, the IEE regulations only refer to the following:

❑ Fuses – BS 3036, BS 88, BS 1361 and BS 1362
❑ Circuit breakers BS 3871 and BS EN 60898

brass flat
pin terminals

porcelain
holder

plastic
backplate

fuse wire threaded
through holder
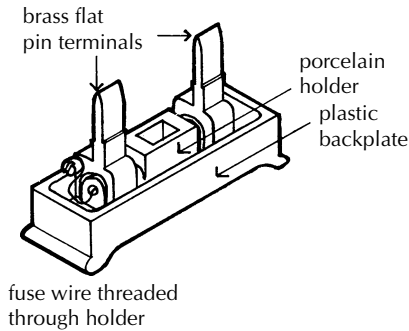
Figure 11.29   Rewirable fuse.

Fuses

The fuse is an overcurrent protective device that is manufactured to 'break' at a pre-determined maximum current, and so break the circuit. The three types of fuse in use are as follows.

Semi-enclosed rewirable fuse (BS 3036)

The semi-enclosed, rewirable fuse (Figure 11.29) consists of a porcelain fuse holder through which the fuse wire is threaded and connected to the two brass terminals. This fuse has lost favour to the cartridge fuse and the circuit breaker, which are easier to replace or reset. Fuse wire is usually rated at 5, 10, 15 and 30 A.

This type of fuse has disadvantages:

❑ Because it is repairable, the wrong size of fuse wire can be used
❑ After long periods of use the elements become weak and may break under normal conditions
❑ Normal starting conditions which result in current surges may overload and break the circuit
❑ The holder can become damaged as a result of a short circuit

Cartridge fuse (BS 1361 and BS 1362)

A cartridge fuse consists of a fuse wire in a tube with metal end caps to which the wire is connected. The fuse wire is surrounded by closely packed granular filler. Figure 11.30 shows a cartridge fuse. These fuses are cheap, easy to replace by pressing into place between terminals and do not deteriorate over time. Cartridge fuses are made with ratings from 2 to 15 A.

High breaking capacity (HBC) fuse

The high breaking capacity cartridge fuse consists of a ceramic tube with brass end caps and copper connecting tags to which the silver elements inside the
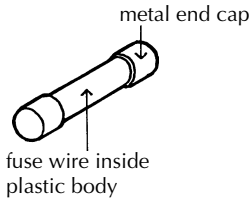
Figure 11.30   Cartridge fuse.

tube are connected. The elements are surrounded by granulated silica filling to absorb the heat generated when the elements overheat, rupture and break circuit. These more sophisticated and expensive fuses are used for the more heavily loaded installations.

Circuit breakers (CBs)
A circuit breaker is a thermal-magnetic, magnetic-hydraulic or assisted bi-metal tripping mechanism designed to operate on overload to break the connected circuit. Miniature circuit breakers (MCBs) are extensively used as protection against damage or danger resulting from current overload and short circuit in final circuits in buildings. MCBs are factory moulded, sealed units available with terminals for plugging in or bolting to metal conductors in consumers' units. A range of ratings are provided to suit the necessary overload current ratings for particular final circuits.

Final circuits
Final circuits are the circuits of a consumer's installation that complete a circuit for the flow of current back to the supply neutral. For the low voltage, single-phase alternating current that is usual for small premises, a small compact consumer's unit will provide distribution terminals for the number of separate final circuits used. Typical circuits for a house could be one or more ring main circuits and one cooker circuit, each with a 30 A breaking capacity fuse or MCB and two or more lighting circuits each with a 5 A fuse or MCB. The purpose of segregating the various circuits is to afford economy in the cost of cables; the cross section of those with 5 A fuses being smaller than those with a 30 A rating. Figure 11.25 shows a typical consumer's unit layout. The length of each circuit is limited to provide an economical section of cable and to minimise the electrical resistance of the cable and the number of connections to each circuit, to limit overload current. The two types of circuit that are used are the ring and the radial.

Ring circuit
These are generally referred to as ring mains and are the most common method of supplying socket outlets in domestic installations in the UK. Ring circuits
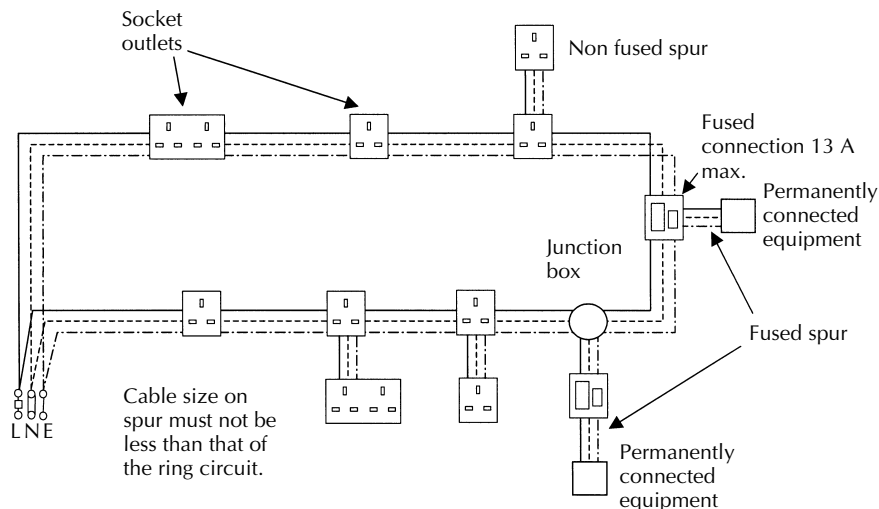
Figure 11.31   Ring circuit.

are commonly used for socket outlets that provide electrical supply to portable equipment. The circuit (Figure 11.31) makes a big loop or ring from one outlet to the next, round all the outlets and back to the consumer's unit, as the most economic and convenient cable layout. The recommended maximum length of cable run depends on the cross section area of conductor chosen and the type of protective device used. While there is no recommended limit to the number of outlets served, it is recommended that a maximum of 100 m² of floor area be served by a ring circuit, protected by a 30 A fuse or MCB in domestic premises. The cable generally used for ring circuits is 2.5 m² conductor, twin and earth, PVC insulated and PVC sheathed cable, or 1.5 m² mineral-insulated copper conductors (MICCs).

Spur outlets from a ring main
Where a socket outlet cannot be conveniently fed by a ring circuit a spur outlet may be run from the ring circuit. A spur outlet is connected through a joint box or spur box, as shown in Figure 11.31. The number of fused spurs is unlimited, and there may be as many non-fused spurs as there are points on the ring main. Each non-fused spur may supply one single-socket outlet, one double socket outlet or one item of permanently connected equipment.

Radial circuits
These are fed from the consumer unit and run either in a loop type formation (lights) or go directly from the source (consumer unit) to a single item of equipment (e.g. a cooker). Typical domestic radial circuits are used for lighting, water, heating, storage heating and cooking.
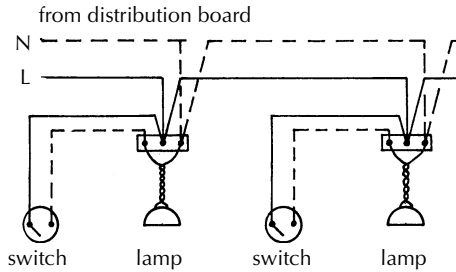
Figure 11.32   Radial lighting circuit.

The loop in system (lighting circuits)

The circuit arrangement for lighting is generally in the form of radial circuits, each of which runs from the consumer's unit to its light fittings and back to the consumer's unit. In each radial circuit the phase conductor runs in the form of a loop from the circuit through a switch back to the light fitting or fittings that the switch controls; the circuit cables 'loop' in and out of each lighting point (Figure 11.32). (For the sake of clarity the CPC cable (earth conductor) is not shown in Figure 11.32). By this arrangement the switch controls the fittings allocated to it without controlling the rest of the light fittings connected to the circuit. Where one switch is used to control several light fittings the circuit may be run as a ring circuit off a radial circuit, or as a ring circuit by itself, whichever is the most convenient. A 5 A fuse or MCB is connected as an overcurrent protective device to the phase wire run out from the consumer's unit. The cables are run in 1.5 mm^2 conductor, twin and earth, PVC insulated and PVC sheathed cable. To limit current flow to suit the fuse or MCB and cable size, there are usually two or more separate lighting circuits to most small installations.

Short circuit

A short circuit is a fault in a circuit where a live conductor comes into contact with another. A short circuit may cause overheating of conductors and break-down of insulation and so damage the electrical installations. Overcurrent protective devices, such as fuses and MCBs, are fitted to limit the occurrence of a short circuit.

Earthing

The Wiring Regulations (BS 7671:2001) include recommendations for protection against the dangers of electric shock to persons or livestock, damage to installations and the danger of fire from overcurrents and earth faults. The earth conductor in cables and the earthing connections to conductive metals provide an alternative path for unplanned flows of electrical energy.

Electric shock from direct contact is caused when a person comes into contact with a live electrically charged part, which causes a current to flow through them to earth. This is likely to cause injury that may be fatal. Direct contact with a properly designed installation is unlikely. Indirect electric shock occurs when the electrical cable within an installation makes contact with its metal casing. The casing is not normally live but may have become so under earth fault conditions caused by contact of a live conductor coming into contact with a metal casing due to insulation failure. The circuit protective conductor (CPC), often called the earth cable, is connected to metal components of electrical appliance so that, in the event that a fault occurs, unpredicted currents have a direct flow to earth through the CPC, earth cable, rather than through a person.

With the generally used TN-C-S system of supply cables, the earth (CPC) conductor of an installation is connected to the combined neutral earth of the supply cable, which may not provide a wholly satisfactory path to earth. It is generally necessary, therefore, to provide other earth paths through earth electrodes connected to the installation's earthing block.

Main equipotential bonding
BS 7671 requires that all extraneous conductive metal parts, which are not part of an electrical installation, be connected to the main earthing terminal (MET). This earth bonding is provided as protection against the possibility of conductive metal outside (extraneous) the electrical installation becoming live due, for example, to failure of insulation of a cable run close to a heating pipe, making a live connection to the pipe. The conductive metals included are water, gas, oil, heating and hot water pipes, radiators, air conditioning and ventilation ducts, which should be earth bonded as illustrated in Figure 11.33.

Most modern units have an integral earth bar, which can accommodate all of the circuits' earths or circuit protective conductors (CPCs), the main earthing conductor and the main equipotential bonding conductors.

Cross bonding
The purpose of equipotential bonding is to co-ordinate the characteristics of protective devices with earthing and the impedance (resistance) of the circuit to limit touch voltages until the circuit protective devices cause disconnection. Because of the introduction of plastic pipes, connections and plastic coatings to metal, it may be necessary to provide earth bonding connections across any plastic parts.

Bathrooms
Special consideration needs to be given to the position of electrical sockets and appliances in bathrooms. Different considerations are given to zones that are in close proximity to wet appliances and those that are further away from the wet appliances. Bathrooms are divided into four zones: 0, 1, 2 and 3. Zone 0 is the
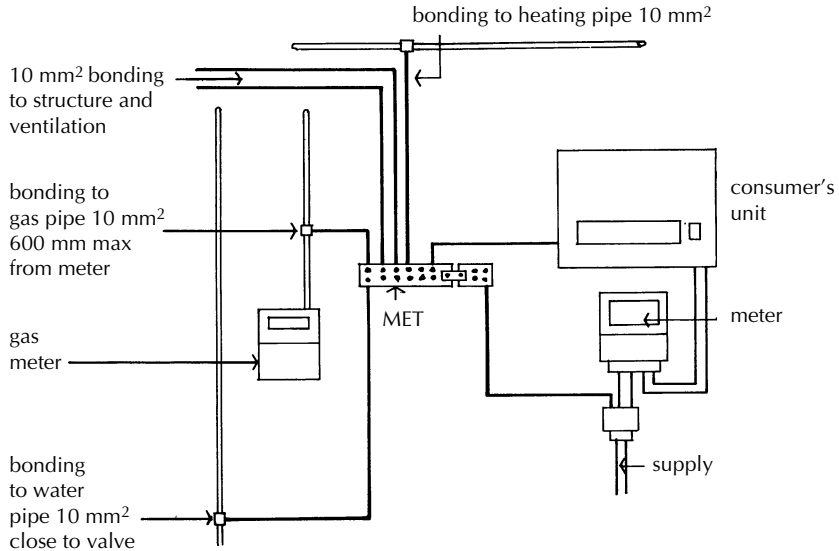
Figure 11.33   Equipotential bonding.

interior of the bath tub or shower basin; if the shower flows into a wet room with no shower tray, the zone is applied to a radius of 600 mm from a fixed head shower or 1200 mm radius for demountable head showers, at a depth of 50 mm above the floor (Figure 11.34).
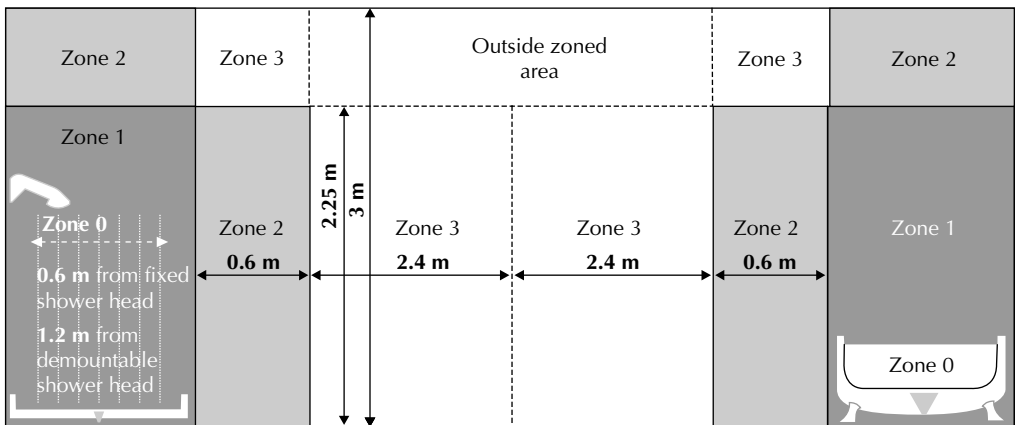
Zone 0 = in the shower tray and 50 mm

Figure 11.34   Bathroom zones.

Factors and considerations associated with this zone:

❑ Only SELV 12 V (Separated Extra Low Voltage), or ripple free d.c. may be used as a measure against electric shock, the safety source being outside zones 0, 1 and 2.

❑ No switchgear or accessories are permitted, other than equipment that is specifically designed for use in the zone. Equipment must be at least IP X7 (index of protection code). IP 7X means that the installation should be protected against immersion in water. It must not be possible for water to enter the enclosure.

❑ Only wiring associated with specifically designed equipment may be installed.

Zone 1

This is the area that is above and below the zone 0 area. Zone 1 extends to 2.25 m above the floor where zone 0 area applies. Factors and considerations associated with this zone are:

❑ Only SELV (Separated Extra Low Voltage) switches and switches and controls specifically designed for use in this area are permitted.

❑ Water heaters and shower pumps can only be used provided they are specifically designed and suitably fixed for use in this zone.

❑ All equipment installed must be suitable for this zone and must be protected by an RCD (rated tripping current of 30 mA or less).

❑ Only wiring that is suitable for use in zone 0 and 1 should be installed.

❑ Equipment designed for use in zone 1 must be at least IP X4 (protection against splashing; liquid which is splashed from any direction should have no harmful effect) or IP X5. (The installation should be protected against water jets, which may be projected from any angle. The water jets should have no harmful effect.)

Zone 2

Zone 2 extends 600 mm horizontally beyond zone 1 and covers the area above zone 1 to a height of 3 m above floor level. Thus zone 2 is the area above zone 1 from 2.25 m to 3 m above floor level. Factors and considerations associated with this zone are:

❑ Only switches and socket outlets of SELV circuits and shaver units to BS EN 60742, and equipment specifically designed for used in this zone may be installed.

❑ Only water heaters, shower pumps, lights (luminaries), etc. designed for use in this zone should be installed.

❑ Insulating pull cords may hang down into zones 1 and 2 but the main body of the switch must be in zone 3 or outside the zoned areas.

❑ Equipment designed for use in zone 2 must be at least IP X4 (protection against splashing; liquid which is splashed from any direction should have no harmful effect) or IP X5. (The installation should be protected against water jets, which may be projected from any angle. The water jets should have no harmful effect.)

Zone 3
Zone 3 extends 2.4 m beyond zone 2 and is extended to a height of 2.25 m above the floor level. Factors and considerations associated with this zone are:

❑ Only SELV sockets or shaver units to BS EN 60742 may be installed in this zone. Equipment must be specifically designed for use in this zone, or must be protected by an RCD (rated tripping current 30 mA or less).
❑ Any equipment designed for use in this zone must be at least IP X5, if water jets are likely to be used. IP X5 means that the installation should be protected against water jets, which may be projected from any angle. The water jets should have no harmful effect on the installation.

Supplementary equipotential bonding
It is a requirement of BS 7671 that supplementary equipotential bonding is provided to all simultaneously accessible, exposed conductive parts in special conditions of wet activities and high humidity, such as bathrooms and swimming pools, where the moisture in such conditions provides additional risks. The term 'simultaneously accessible' in relation to exposed conductive parts means the possibility of someone, for example in a bath of water, reaching out to touch a heated, metal towel rail and so providing a conductive path from the metal bath to the towel rail, through their body. The purpose of supplementary bondings is to spread the voltage potential across and between other adjacent bonded metal parts to equalise and so limit the voltage potential to that least likely to cause injury or death in the few seconds before circuit breakers come into operation.

A bath is the appliance most requiring supplementary bonding between metal pipes and a metal waste pipe, as shown in Figure 11.35. Bonding to a basin is required between metal hot and cold water pipes and a metal waste pipe. Similarly a metal supply pipe to the cistern of a WC should be bonded to a metal waste pipe. To complete the supplementary bonding between all simultaneously accessible exposed conductive parts, there should be bonding between the cross bonding to a bath, basin, WC and a radiator. This connecting bonding may be affected by a conductive pipe that provides a link to sanitary fittings. Where there is no satisfactory conductive link by pipework, conductive bonding should be connected to all bonded fittings and connected to the radiator as a terminal.

To effect supplementary bonding a conductor should be connected between simultaneously accessible, exposed conductive parts by means of pipe clamps,
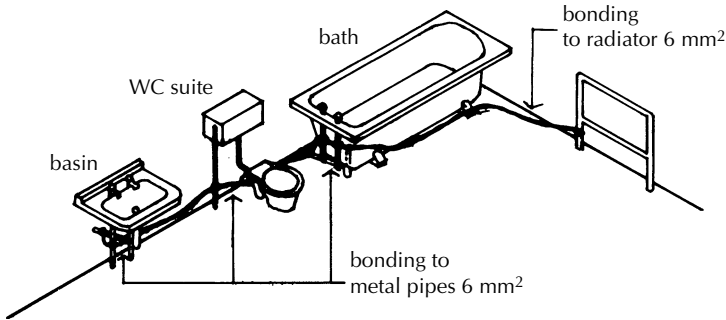
Figure 11.35   Supplementary equipotential bonding.

through which the conductor should run continuously. The bonding conductor may be of bare copper or insulated copper, the lowest cross sectional area of which should be 4 mm^2. Because it is a requirement that supplementary bonds be accessible for inspection and testing, there may well be some untidy exposed conductors and pipe clamps that cannot be hiden behind removable bath panels or basin pedestals. Supplementary bonding must be carried out with equipment and any extraneous conductive part within zones 1, 2 and 3.

Cables and conduits

PVC cable – twin and earth
The cable most used for final circuits to 240 V, single phase supplies is PVC insulated, PVC sheathed cable (commonly described as PVC twin and earth, describing the phase and neutral insulated conductors and the earth in the sheath), as shown in Figure 11.36. The size of the cable is defined by the cross sectional area of the copper wires: 1.5 mm^2 and 2.5 mm^2 for lighting and socket outlet circuits respectively. For 415 V, three phase supplies, a three core PVC insulated and sheathed cable is used.
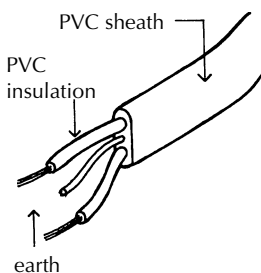
Figure 11.36   PVC insulated, PVC sheathed cable.

Protection

The Wiring Regulations provide extensive recommendations on measures to be taken to minimise damage to cable during installation and in use. These may be broadly grouped under the headings mechanical damage, temperature, water and materials in contact including corrosive materials. Mechanical damage includes precautions to avoid damage during installation, such as drilling holes in the centre of the depth of floor joist for cable runs rather than using notches in the top or bottom of joists where subsequent nailing might damage cable. At comparatively high and low temperatures plastic may soften or become brittle respectively, and so weaken. At temperatures above 70°C, plastic will appreciably soften, and below freezing will become noticeably brittle and crack. Water, both as liquid and in vapour form, in contact particularly with terminals, may act as a conductor between live and live and live and earth conductors. To protect cables from damage by corrosive materials such as cement, cables run in plaster, concrete and floor screeds should be protected by channels or conduit.

Mineral insulated metal sheathed cable

This type of cable consists of single-stranded wires tightly compressed in magnesium oxide granules, enclosed in a seamless metal sheath of copper or aluminium, as shown in Figure 11.37. The combination of the excellent insulation of the magnesium oxide and the metal sheath gives this cable an indefinite life and reasonable resistance to mechanical damage. For added protection the metal sheath may be protected with a PVC sheath. Because of the high initial cost of the cable and the various fittings and seals necessary at bends, junctions and terminations, the use of this cable is confined to commercial and industrial installations where the cost may be justified. The metal sheath may serve as the earth (CPC) conductor.

Channels

Channels of plastic or galvanised steel, generally in the form of a hat section, are used to provide PVC cable, which is to be buried in plaster, with protection
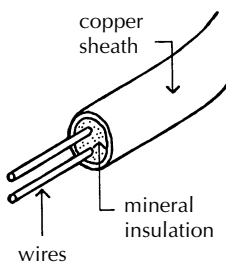
Figure 11.37   Mineral insulated copper sheathed cable.

and to secure the cable in position while the plaster is being spread. The brim of the hat section is tacked to the wall surface around the cable. These sections, which are used solely as protection, do not provide a ready means of pulling cable through when replacing cable.

Conduit

Round or oval section plastic or galvanised steel sections are used as protection where PVC cable is to be run in plaster, solid floors, walls and roofs. Conduit is used to provide all round protection, particularly where the cheaper PVC insulated cable is used, and to provide a means of renewing and replacing cable by drawing cable through the conduit. Because of the bulk of the conduit it is generally necessary to form or cut chases (grooves) in wall surfaces and solid floors and roofs where screeds are insufficiently thick to accommodate the conduits.

Plastic conduit

Plastic conduit, which is considerably cheaper than metal conduit, is made in round or oval sections. Round section conduit, which can be buried in thick screeds, has to be fixed in a chase or groove in walls. Oval section conduit can be buried in thick plaster finishes and thin screeds. Lengths of conduit are joined by couplers, such as the one shown in Figure 11.38, into which conduit ends fit. A limited range of elbows and junctions is made for solvent welding to conduit. The conduit is secured with clips that are tacked in position. There is some facility for pulling through replacement cable, but not as much as with metal conduit. Because it is made from plastic, the conduit will not serve as earth conductor.

Metal conduit

Metal conduit is manufactured as steel tubes, couplings and bends which are either coated with black enamel or galvanised. The cheaper black enamel conduit
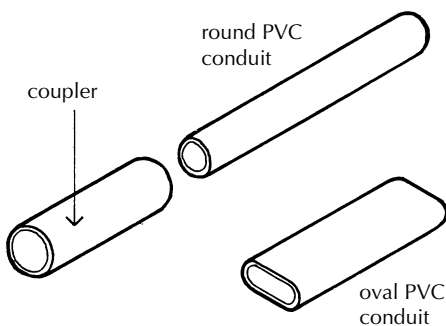
Figure 11.38   PVC conduit.
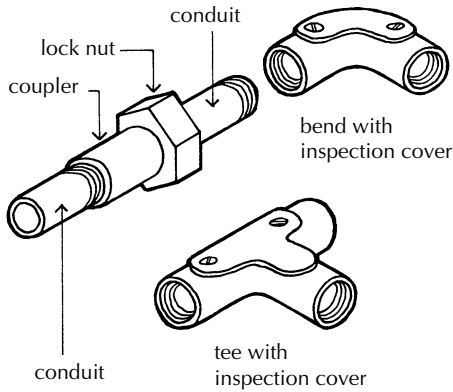
Figure 11.39   Steel conduit.

is used for cables run in hollow floors and roofs and other dry situations. The more expensive galvanised conduit is used where it is buried in concrete floors, roofs and screeds and for chases in walls below plaster finishes where wet finishes might cause rusting if black enamel conduit were used. Metal conduit is produced with a variety of fittings designed to facilitate pulling out old cable and replacing it with new. The access or inspection covers to the bend and tee, shown in Figure 11.39, are for pulling through. Because the conduit is of conductive metal it may serve as the earth (CPC) conductor, and single PVC insulated cable may be used as the conduit provides protection against damage.

Trunking

Where there are extensive electrical installations and several comparatively heavy cables follow similar routes, with standard conduit too small to provide protection, it is practice to run cables inside metal or plastic trunking to provide both protection and support for the cables. Trunking is fixed and supported horizontally or vertically to wall, floor or ceiling structures, or above false suspended ceilings, with purpose-made straps secured to the structure. Trunking is also run inside ducts for vertical runs and above false ceilings where appearance is a consideration, or it is exposed in industrial premises. Trunking may be hollow, square, rectangular, circular or oval in section. Figure 11.40 is an illustration of square trunking with access for inspection and any necessary renewal or alterations.

Socket outlets

Socket outlets comprise sockets in a wall-mounted front plate into which the terminals of a loose plug top fit to supply electricity to a wide range of moveable, portable and hand held electrical equipment. Socket outlets are usually connected to a ring final circuit, there being no limit to the number of sockets
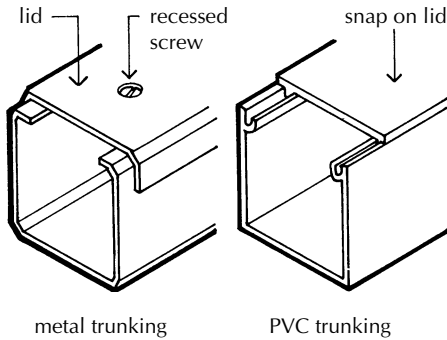
Figure 11.40   Metal trunking.

connected to each ring circuit, which should not serve an area greater than $100\,m^2$ for domestic installations. A ring circuit is protected by a 30 A fuse or MCB at the consumer unit.

A socket outlet consists of a galvanised steel box to which a front plate is screwed after the terminals of the front plate have been connected to the electric supply cable. The galvanised, pressed steel boxes are made with circular knockouts, which can be removed for cable entry, and lugs for screws to secure the plastic front plate. Steel boxes are usually made for recessing into a wall and plaster and others for surface fixings. Figure 11.41A shows a recessed steel box for a two gang, two plug top outlet. Steel boxes for surface fixing have a smooth faced finish with the knockouts for cable entry and holes for fixing screws in the back of the box. Figure 11.41B shows a steel box for surface mounting. Front plates to socket outlets are moulded from plastic to suit single, double or multi-gang plug top outlets, complete with sockets for square three pin plug tops. Brass terminals for the phase, neutral and earth conductor cables are fixed to the back of the front plate, and it is holed for two screws for fixing to the steel box. Socket outlets may be supplied with a switch and a pilot light to indicate the 'on' position (Figure 11.41C).

Many socket outlets are connected to a ring circuit, which is protected with a 30 A fuse or MCB at the consumer unit. It is necessary to fit a cartridge fuse to the plug top to provide current overload protection to the flexible cord and appliance connected to the outlet. Fuses to plug tops to outlets vary from 2 or 4 A for lighting to 13 A for electric fires. Where there is a spur branch to a ring circuit a spur box is fitted to provide a connection for the spur cables and to protect and control the spur outlet. A spur box consists of a steel box and plastic front plate in which is a fuse and a switch (Figure 11.42). The terminals at the back of the front plate serve to make connection of the spur cables.

The electrical supply to an electric cooker with hobs, grill and oven requires a high fuse rating and cables. A separate radial circuit is run from the consumer's unit to the electric cooker, and protected by a 30 A fuse or MCB in the consumer's
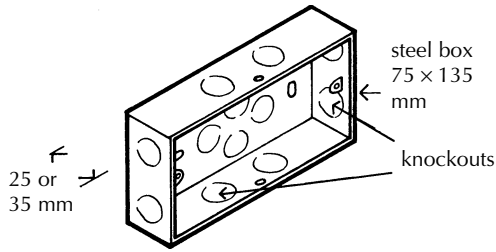
A. 2 gang steel box
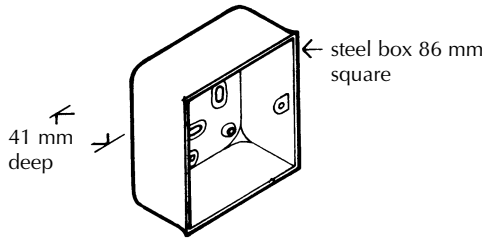
B. Steel box for surface mounting
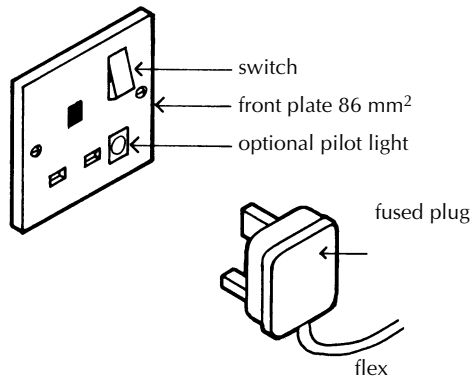
C. 13 A outlet and plug

Figure 11.41   Socket outlets.
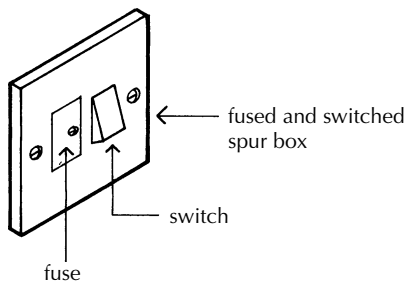
Figure 11.42   Spur box.
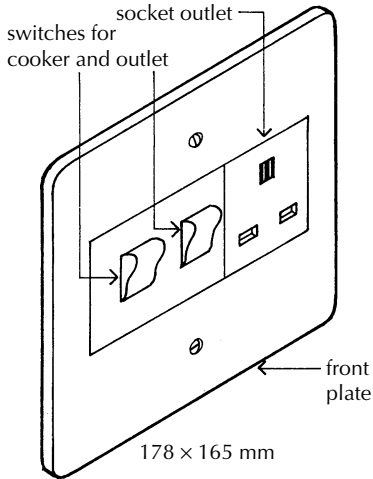
Figure 11.43   Cooker control unit.

unit. A wall mounted cooker control unit is fixed close to the cooker. This control unit consists of a recessed steel box and plastic front plate in which a single switch or two switches and a socket outlet are provided, as shown in Figure 11.43. The socket outlet in the cooker control unit is for such portable equipment as an electric kettle. The two switches control the cooker and the socket outlet.

11.6 Artificial lighting

Artificial lighting is important to enable us to carry out tasks safely and as a means of creating ambience within a room. In an attempt to minimise use of electricity there has been much encouragement to the public to fit low energy light fittings. This drive to minimise energy use has now become mandatory through the most recent Approved Document Part L of the Building Regulations. Non-domestic buildings are required to provide lighting systems that are energy efficient. Part L gives guidance on how this can be achieved. The regulations apply to new dwellings and those where there has been a material change of use.

Energy efficient lighting

The Building Regulations require that a minimum number of energy efficient lamps should be used within a dwelling. As a general rule at least one provision for energy efficient lighting should be provided for every three rooms in a dwelling. Lamps with a circuit luminous efficacy greater than 40 lumens/watt (lm/W), e.g. compact fluorescent lamps (Class A type) with special lampholder

(other than screw or bayonet fitting), so that the lamp cannot be replaced with a standard lamp, are suitable.

Energy efficient lighting should also be used in non-domestic buildings. The requirements imposed by Approved Document L2 are much more detailed. They aim to make greater use of natural light, avoid lighting areas that are not in use and increase use of energy efficient lighting without endangering occupants using the buildings. Switching devices that can help achieve these requirements include:

❑ Local manual controls so that lights can be turned off when the area is not in use
❑ Absence detection (device turns off when room is not in use)
❑ Timed off control (provides light for set time then turns off – could be set to minutes or hours)
❑ Photoelectric dimming (lights dim when the natural light increases)
❑ Photoelectric switching (lights turn off when the natural light is sufficient)

By using a combination of energy efficient lamps and controls the requirements of the Building Regulations can be met.

External lighting

Where external lighting is fixed to a building, such as lamps over porches, reasonable provision should be made to enable effective control and efficient use of lamps (Approved Document L1). One method of complying with this regulation is to install systems that:

❑ Automatically extinguish when there is enough daylight, and when not required at night (e.g. on a timer), or
❑ Have sockets that can only be used with lamps having an efficacy greater than 40 lumens per circuit (e.g. compact fluorescent lamps).

For lighting paths, driveways and other external areas, low-voltage systems are available and freestanding lights operated by solar cells (with a back-up battery) may be an energy saving alternative.

Lighting outlets

Common for high ceilings is a ceiling rose screwed to the ceiling, from which drops a pendant cable supporting a lamp holder fixed at a convenient height. The ceiling rose is connected to a radial circuit protected by a 5 A fuse in the consumer unit, with a loop down to a wall switch that controlls the ceiling light (Figure 11.44A). Because a pendant lamp is unsuited to the lower ceiling height of most modern domestic buildings, a batten lampholder may be used for single ceiling lamps or one of the many lighting fittings designed to fit
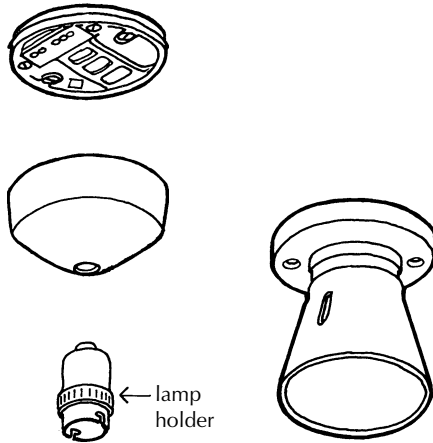
A. Ceiling rose and lampholder   B. Batten lampholder

Figure 11.44   Ceiling lampholders.

closely to ceilings. The batten lampholder shown in Figure 11.44B is assembled as a single unit with the lampholder close to the ceiling. The three cables, phase, neutral and earth, are connected to the terminals in the base, which is screwed to the ceiling. The lampholder is screwed to the base and the lampholder cover screwed around the lampholder.

More intense lighting systems used for display purposes in shops and showrooms have been used in the home for kitchen and general lighting. Systems of 'downlighting' have been used, consisting of a number of lights recessed into ceilings and systems of 'spotlighting', using lamps fixed to tracks in the ceiling, which may be adjusted to light a particular area. There have been rapid advances in the range of affordable halogen light fittings suitable for all types of building use.

Wall switches

A wall switch is generally recessed in a wall, partition or plaster depth for appearance sake. A galvanised, pressed steel box is set into a recess in the wall after knockouts have been removed for the cable entry. The three conductors, phase, neutral and earth, are connected to the terminals set into the back of the plastic front plate, which is then screwed to lugs in the steel box. Figure 11.45 shows a single gang switch, with steel box and plastic front plate. For small rooms a single switch inside the access door or opening is generally sufficient for ceiling and wall lighting. For large area rooms it is often convenient and economical to use two or more circuits, each with its own wall switch, so that a part of, or the whole of, the room may be illuminated. For staircases a system of two way or three way switching to a circuit is used to control the lighting

25 or 35
mm deep

16 mm

steel box
75 mm²

steel box
72 mm²

front plate
86 mm²

1 gang switch

3 gang switch

knockouts

steel box and lighting switch

**plaster depth
steel box and lighting switch**
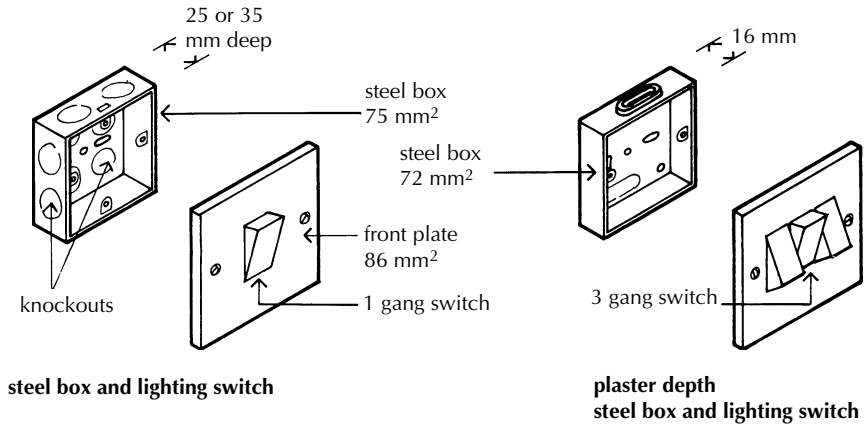
Figure 11.45   Wall switches.

on upper and lower floors as necessary. The system of two way or three way switching involves additional wiring to provide the means of switching from two places. Figure 11.45 is an illustration of a steel box and plastic front plate for a three gang switch.

Further reading

Scaddan, B. (2003) *Electrical Wiring Domestic*, *12th* edn, London, Newnes.

12   Water Supply, Sanitation and Refuse Disposal

Water supply, sanitation and refuse disposal are at the heart of our sustainable future. We all use too much water and generate too much waste and with the increasing population it is likely that our sewers and infrastructure will experience considerable difficulty in coping with our demands. To ensure that good standards of hygiene are maintained around buildings, it is essential that care be taken when designing, installing and commissioning the services that will be used to supply water and remove our waste.

12.1 Water supply and distribution

Water supply

Mains water suppliers, the water undertakers, have an obligation to provide a constant, potable (drinkable) supply of water, for which service either a water rate is levied or a charge by meter is made based on the volume of water used. All new premises and an increasing number of existing houses have a water meter fitted to measure water consumption. Water is supplied, under pressure, through pipes laid under streets, roads or pavements. In urban areas duplicate trunk mains feed street mains. By closing valves individual lengths of main may be isolated for repairs and renewals without interrupting the supply.

Functional requirement
The functions of water supply are to:

❏ Deliver clean water suitable for human consumption (Fluid Category 1)
❏ Provide a continuous supply of water at a constant pressure

**Water Categories and prevention of cross connection
to unwholesome water**
The quality of water is determined by five fluid categories, the highest Category 1 being the cleanest, 'wholesome' water suplied by a water under-taker and suitable for drinking, through to Fluid Category 5, which represents a serious health hazard.

All water fittings that convey unwholesome water, for example rainwater, recycled water or any fluid other than water supplied by a water undertaker,

608

must be clearly identified so as to be easily distinguished from any supply pipe or distributing pipe. This is to avoid any contamination of the water supply, and is particulary important where systems are designed to use 'grey' water (e.g. for flushing toilets).

Connections to the water main

Service pipe

The water undertaker makes connections to the existing main. The service pipe connection is made to the main and is run to a stop valve near to the site boundary of the building; maintenance is the responsibility of the water undertaker. A stop valve is situated either immediately outside or inside the boundary. The purpose of the stop valve is to enable the water undertaker to disconnect the water supply if there is a leak or for non-payment of the water bill. In situations where the supply is provided to two or more premises from the same supply or distributing pipe then it should be fitted with a stopvalve to which each occupier of those premises can have access.

Supply pipe

A supply pipe is any pipe, maintained by the consumer, that is subject to water pressure from the authority's mains. The pipe that is run from the stop valve to, and into, the building is termed a supply pipe; maintenance is the responsibility of the land/building owner. For convenience it is usual to run the supply pipe into the building through drainpipes to facilitate renewal of the pipe if need be. At the point that the supply pipe enters the building there should be a stop valve (see Figure 12.1), to disconnect the supply for repair and maintenance purposes. To reduce the risk of freezing, the supply pipe should be laid at least 750 mm below the finished ground level. If the supply pipe enters the building and rises closer than 750 mm to the outside face of a wall, it should be insulated from where it enters the building and up to the level of the ground floor.
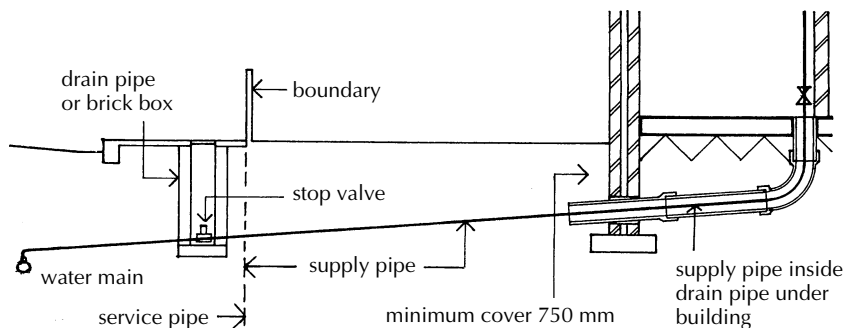
Figure 12.1   Service pipe and supply pipe.

Distributing pipe

A distributing pipe is any pipe (other than an overflow or flush pipe) that conveys water from a storage cistern or from hot water apparatus supplied from a feed cistern and under pressure from that cistern.

The Water Supply (Water Fittings) Regulations 1999

These Regulations apply to any water fitting installed and used in premises to which a water undertaker supplies water. The Act deals with the installation and enforcement of water supply and water fittings, providing guidance on materials and substances in contact with water, workmanship, water system design and installation and provision against backflow (and hence potential contamination) of the water supply. The Act also sets out clear advice about the way in which water fittings are installed within a building, clearly stating that no water fitting shall be embedded in any wall or solid floor thus allowing access for maintenance and repair.

   The principal concern of the byelaws is the prevention of contamination of mains supplied water by the flow of potentially polluted water from a supply or distributing system back into the mains water supply. Flow of water from a supply or distributing system back into the mains supply can occur when there is loss of pressure in the mains due to failure of pumps, or repair and maintenance on the mains, and also where a pumped supply in a building creates pressure greater than that in the mains. As a guard against backflow, all draw-off taps to baths, wash basins and sinks must either be fixed so that there is an air gap between the spill-over level of the fittings and the outlet of the tap, as illustrated in Figure 12.2, or a double check valve assembly must be fitted to the supply pipe to each draw-off tap. These requirements apply equally to taps connected to mains pressure supply pipes and to distributing pipes from a cistern. The Act also requires water supply for outside use to comply with provisions to save water and prevent contamination; this includes drinking water for animals and supply to ponds and pools.

Water system design and testing

The complete water system (all pipes and relevant fittings) must be designed to withstand an internal water pressure of not less than one and a half times the
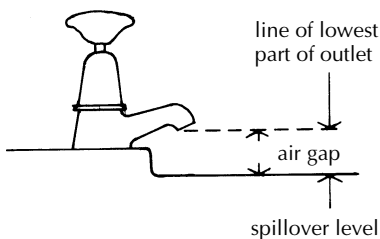
Figure 12.2   Air gap to taps to fittings.

maximum pressure to which the installation is designed to be subject to when in operation. The Water Supply (Water Fittings) Regulations provide advice on the type of testing required, which differs for systems that do include a pipe made of plastics and those that do not. The whole system should be subjected to test pressure by pumping and subsequent maintenance of test pressure for a stipulated period (e.g. one hour in the case of systems that do not contain plastic pipes) to check for any visible leakage. After testing every water system should be flushed and, where necessary, disinfected before it is first used.

Cold water supply systems

The two systems of cold water supply that are used are indirect, from a cold water storage cistern and direct, from the mains water pressure. The advantages and disadvantages of the systems are as follows.

Cistern feed – indirect supply
Advantages:

❑ The reserve of water in the cistern that may be called on against interruption of supply to provide regular flow
❑ The air gap between the supply pipe and the water level in the cistern acts as an effective barrier to backflow into the mains supply, which can cause contamination

Disadvantages:

❑ The considerable weight of a filled cistern has to be supported at high level
❑ The inconvenience of access to the cistern for inspection and maintenance
❑ The possibility of the cistern overflowing
❑ The need to insulate effectively the cistern and its associated pipework against freezing
❑ Animals and insects may enter the cistern and contaminate the water held in the open cistern

Mains pressure – direct supply
Advantages:

❑ A uniformly high-pressure supply to all hot- and cold-water outlets some distance below the pumped head of the supply

Disadvantages:

❑ Discontinuity of supply to all hot- and cold-water outlets if mains supply is interrupted
❑ The need for comparatively frequent inspection, maintenance and repair of many valves and controls to the system
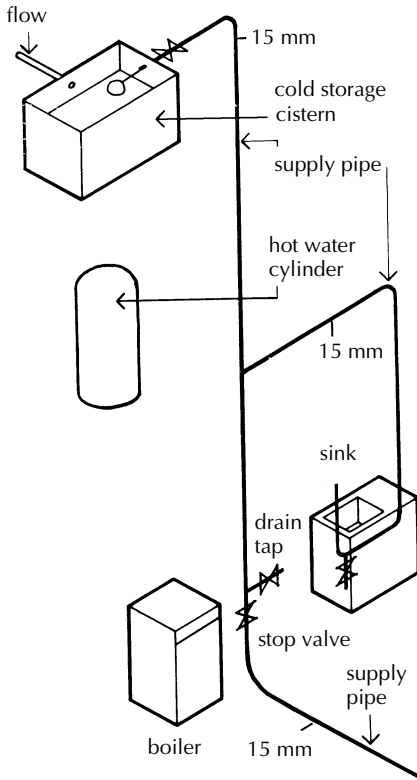
Figure 12.3   Cistern feed cold water supply.

Cistern feed cold water supply

A cistern is a liquid storage container that is open to the air and in which the liquid is at normal atmospheric pressure. Figure 12.3 illustrates the cold water supply to a two-storey house. The supply pipe rises through a stop valve and draw-off or drain tap to the ball valve that fills the cistern. A stop valve is fitted close to the cistern to shut off the supply for maintenance and repairs.

Small capacity cisterns are used as header or feed tanks to provide the necessary head of cold water supply to boilers where an open vented pipework system is used. The header or feed cistern or tank is fixed in a roof space or in some position above the boiler to provide the necessary head of water. An expansion pipe runs up from the boiler, to discharge over the header tank, so that water under pressure from overheating may discharge into the header tank. The majority of cisterns are manufactured in plastic materials, which do not rust and are easy to handle when empty (Figure 12.4). Many existing buildings

Polypropylene cistern

**Circular glass
reinforced polyester
cistern**
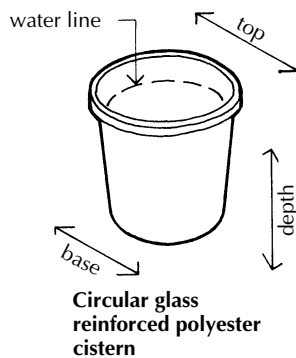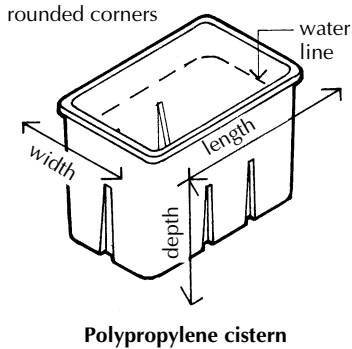
Figure 12.4   Plastic cisterns.

still have galvanised steel cisterns, which are prone to rust, and which should be checked regularly and replaced where necessary.

The most convenient place for a cold-water storage cistern is in a roof space below a pitched roof, or in a tank room on a flat roof or at some high level. In whichever position the cistern is fixed, there must be space around and over the cistern for maintenance or replacement of the ball valve. The cold water storage cistern must be fixed not less than 2 m above the highest fitting it is to supply with water. This distance represents the least head of water necessary to provide an adequate flow.

Because of the weight of water they are designed to contain, all cisterns must be adequately supported on timber or steel spreaders to transfer the load over a sufficient area of timber or concrete ceilings and roofs, as illustrated in Figure 12.5.

The capacity of cold water storage cisterns is usually 114 litres per dwelling where the cistern supplies cold water outlets and WC cisterns, and 227 litres per dwelling where the cistern supplies both cold water to outlets and domestic
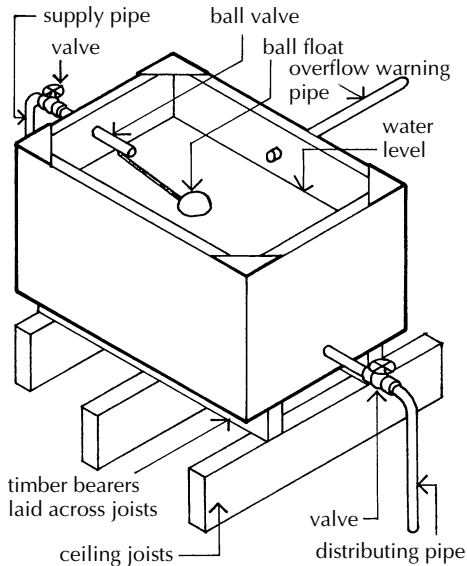
Figure 12.5   Support for cistern.

hot water cylinders. The alternative is to calculate the capacity of the storage cistern at 90 litres per resident. Cisterns are holed for the connection of the cold water supply, the distributing pipes to cold water outlets, and for the pipe to a hot water cylinder and the overflow pipe.

Ball valve

The water supply to the cistern is controlled by a ball valve that is fixed to the cistern, above the water line, and connected to the cold supply through a valve as illustrated in Figure 12.5. A hollow copper or plastic ball, fixed to an arm, floats on the water in the cistern; as water is drawn from the cistern, the ball falls and the arm activates the ball valve that opens to let water into the cistern. When the water has risen to the water line, marked on the cistern wall, the ball and arm rise to close the valve. The two types of valve in use are the Portsmouth valve and, for most new installations, the diaphragm valve, see Figure 12.6.

To prevent contamination of mains supply of water by back siphonage, back-flow or cross connection, an air gap between the outlet of float valves to cisterns and the highest water level in the cistern is required. This air gap is related to the bore of the supply pipe or the outlet and is taken as the minimum distance between the outlet of the float valve and the highest water level when the overflow pipe is passing the maximum rate of inflow to the cistern (Figure 12.7).
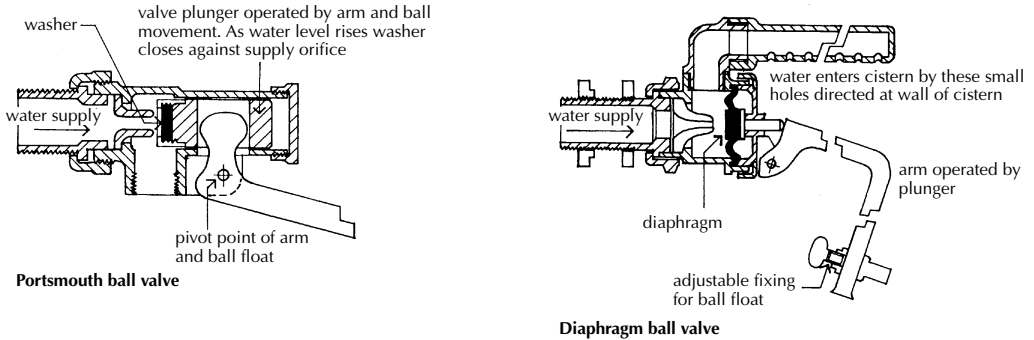
Figure 12.6   Ball valves.

Overflow warning pipe

As a precaution against failure of the valve, and consequent overflow of the cistern, most water undertakers require an overflow warning pipe to be connected to the cistern above the water line and carried out of the building to discharge where the overflow of water will give obvious warning. The overflow pipe should be of larger bore than the supply pipe to the cistern and preferably twice the bore of the supply pipe and not less than 19 mm bore.

Cistern feed cold water distributing pipe system

Figure 12.8 illustrates the cold water distributing pipe system for a two-storey house. The distributing pipe is connected to the cistern some 50 mm above the bottom of the cistern to prevent any sediment that may have collected from entering the pipe. A stop valve is fitted to the pipe adjacent to the cistern, isolating the whole system from the cistern in the event of repairs and renewals. The distributing pipe is carried down inside the building with horizontal branches to the first-floor and ground-floor fittings, as shown in Figure 12.8. The aim in the layout of the pipework is economy in the length of pipe runs, and on this
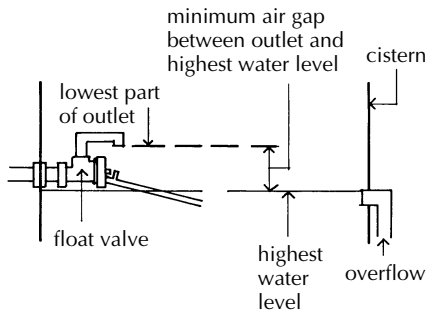
Figure 12.7   Air gap to ball valve.
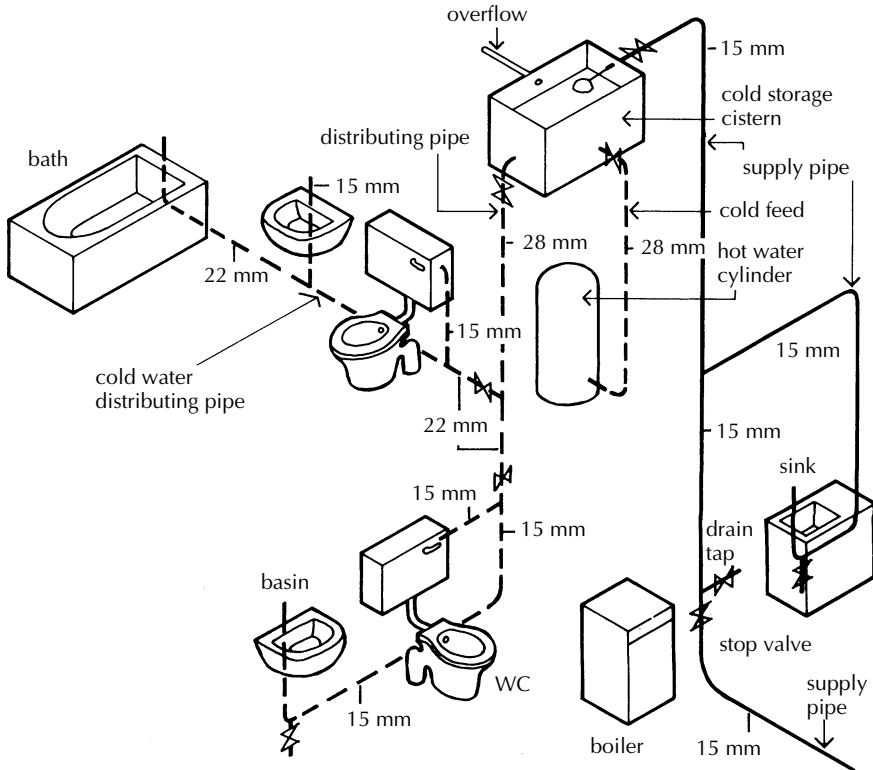
Figure 12.8   Cold water distributing pipe system.

depends a sensible layout of sanitary fittings. In Figure 12.8 it will be seen that one horizontal branch serves bath, basin and WC. For rewashering taps, stop valves are fitted to branches as shown. Where one branch serves three fittings as shown in Figure 12.8, one stop valve will serve to isolate all three fittings. Drain or draw-off taps should be provided where pipework cannot be drained to taps so that the whole distributing system may be drained for renewal or repair.

Cistern feed hot water supply

Figure 12.9 illustrates the hot water distributing pipe system for a two-storey house. The hot water is drawn from a cylinder, which is fed by cold water drawn from the cold water storage cistern in the roof. The cold water in the hot water cylinder is heated by a heat exchanger in the cylinder through which hot water circulates from the boiler. The cold water feed to the cylinder is run through a stop valve to the bottom of the cylinder.

In accordance with the Water Supply (Water Fittings) Regulations, hot water systems should be fitted with appropriate vent pipes, temperature control devices and relief valves.
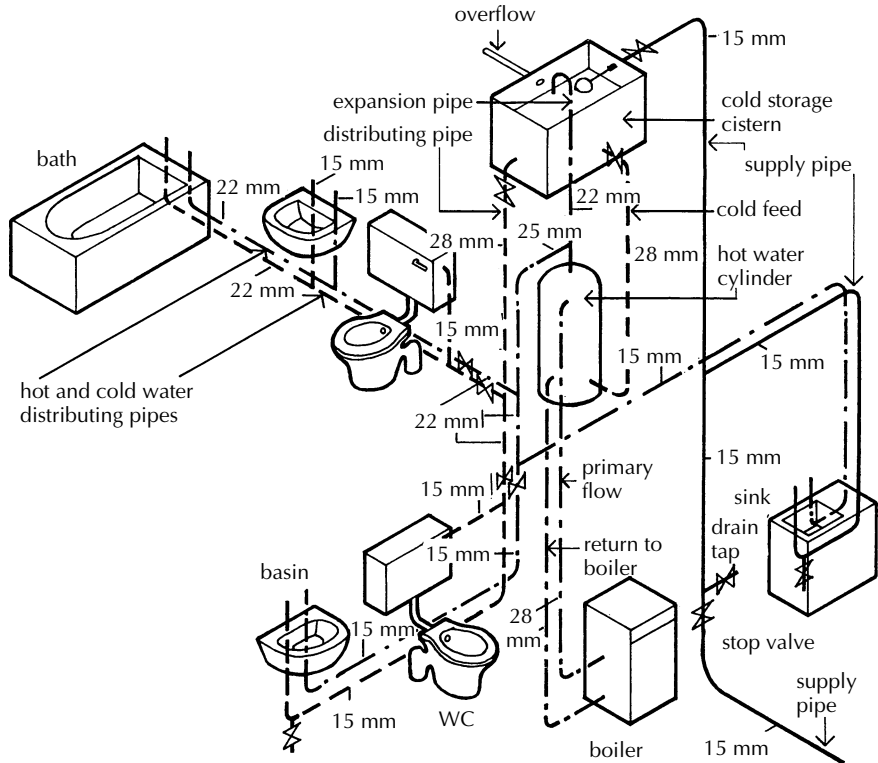
Figure 12.9   Hot water distributing pipe system.

Hot water storage cylinder

Hot water storage cylinders are designed to contain water under pressure of the head of water from the cold water storage cistern. Most hot water storage containers are cylindrical and are fixed vertically to encourage cold water fed into the lower part of the cylinder to rise, as it is heated by the heat exchanger, to the top of the cylinder from which hot water is drawn, and so minimise the mixing of cold and hot water. The cold feed pipe to the cylinder is run from the cold water storage cistern and connected through an isolating stop valve to the base of the cylinder. The hot water distribution pipe is run from the top of the cylinder to the draw-off branches to sanitary appliances and is carried up to discharge over the cold cistern as an expansion pipe, in case of overheating, as illustrated in Figure 12.9.

Vented hot water system

Because the expansion pipe discharges through the open end of the pipe from the cold water storage cistern (if the hot water expands due to the system overheating), this arrangement is described as a vented hot water system and
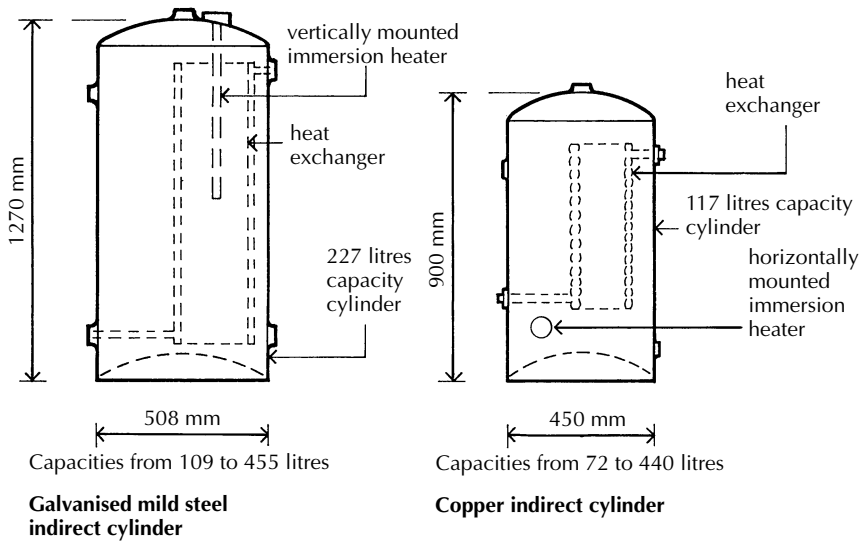
Figure 12.10   Indirect hot water storage cylinders.

the cylinder as a vented or open vented system. This is to distinguish it from the unvented system used with the mains pressure system. The required storage capacity of the cylinder depends on the number of sanitary appliances to be served and the estimated demand. The interval between times of maximum demand on domestic hot water are longer than the recovery period required to reheat water in storage systems, and it is reasonable, therefore, to provide hot water storage capacity of 50 to 60 litres per person. Storage cylinders are made either of galvanised sheet steel or copper sheet welded or riveted, (Figure 12.10).

Indirect cylinder

The hot water storage cylinders illustrated in Figure 12.10 are indirect cylinders, so called because the primary hot water from the boiler exchanges its heat indirectly through a heat exchanger to the hot water supply, there being no connection between the water from the boiler and the hot water supply. The purpose of this indirect transfer of heat is to avoid drawing hot water directly from the water system of the boiler. Where hot water is drawn directly from a boiler it has to be replaced and in hard water areas each fresh charge of water will deposit scale inside the boiler and its pipework and in time the build up of scale will reduce the efficiency of the boiler and the bore to its pipes. With an indirect cylinder there is no replacement of water to the boiler and its primary pipes and therefore no build up of scale. Scale formation is proportional to water temperature. There is less build up of scale in the secondary hot water circulation because of the lower water temperature in the system. Indirect

cylinders are also a protection against the possibility of drawing scalding water directly from the boiler.

Heat exchanger

The heat exchanger, which is fixed inside the cylinder and immersed in the water to be heated, takes the form of a coil of pipes or annulus designed to provide the maximum surface area for heat exchange.

Primary flow

The system of pipes that carries hot water from the boiler through the heat exchanger and back to the boiler is described as a primary flow system.

Hot water boiler or heater

For a small building such as the two-storey house, illustrated in Figure 12.9, it is general practice to use one boiler for both space heating and hot water, to economise in the initial outlay on heating equipment and pipework and to make maximum use of floor space. The temperature of the water heated by the boiler is controlled by a thermostat, which can be set by hand to water temperatures in the range 55 to 85°C, the boiler firing and cutting out as the water temperature falls and then rises to the selected temperature. Water heated in the boiler rises in the primary flow pipe to the heat exchange coil or container inside the hot water storage cylinder and, as it exchanges its heat through the exchanger to the water in the cylinder, it cools and returns through the primary return pipe back to the boiler for reheating. There is a gravity circulation of water in the primary pipe system. The primary flow and return pipes should be as short as practicable, that is the cylinder should be near the boiler to minimise loss of heat from the pipes. The circulating pipes from the boiler through the heat exchanger are termed primary flow and return as they convey the primary source of heat in the hot water system. Small, compact, boilers require a forced flow of water around the primary circulation system by an electrically operated pump. A small feed cistern (not shown in Figure 12.9) provides the head of water required for the boiler and its pipe system.

Immersion heater

An electric immersion heater is fitted to the hot water storage cylinder to provide hot water when the boiler is not used for space heating. An electric immersion heater is an inefficient and relatively expensive means of heating water; however, when powered by PV cells it becomes a more feasible option.

Mains pressure cold water supply

Figure 12.11 illustrates the cold water, mains pressure pipe system to a two-storey house. Here the first line of defence against contamination of the mains supply is a double check valve assembly fitted upstream of the stop valve as the supply pipe enters the building.
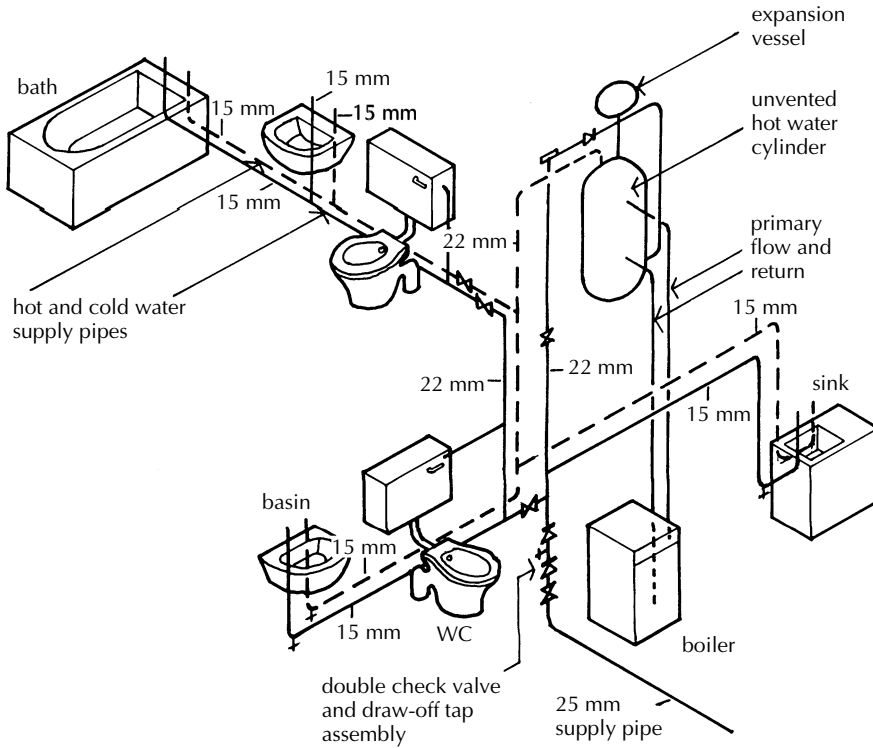
Figure 12.11   Cold and hot water supply.

A check valve, more commonly known as a non-return valve, is a simple, spring-loaded valve that is designed to open one way to the pressure of water against the valve and to close when that pressure is reduced or stops. It therefore acts as a one-way valve that closes against the direction of normal flow and prevents backflow from the supply pipe system into the mains. Figure 12.12 is an illustration of a typical check valve.
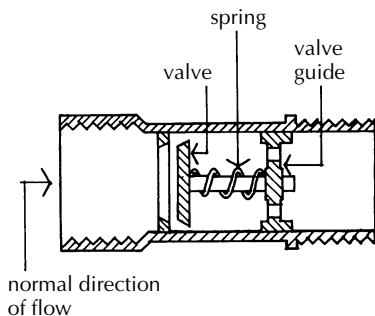
Figure 12.12   Spring loaded check valve, non-return valve.

A double check valve assembly is a combination of two check valves with a test cock between them. A test cock is a simple shut off device with a solid plug that, when rotated through 90°, either opens or closes. In use, a check valve may become coated with sediment, particularly in hard water areas, and not operate as it should. To test that the check valves are working and acting as non-return valves, the stop valve is closed to test one check valve and opened to test the other with the test cock open.

Mains pressure hot water supply

The hot water supply system for a small two storey house is illustrated in Figure 12.13. From the double check valve assembly the supply pipe rises to fill the unvented hot water cylinder with cold water. The cold water in the cylinder is heated by a heat exchanger that exchanges heat from the boiler.

Unvented hot water cylinder
The difference between the traditional vented hot water system and the unvented system is that in the vented system the expansion of hot water is
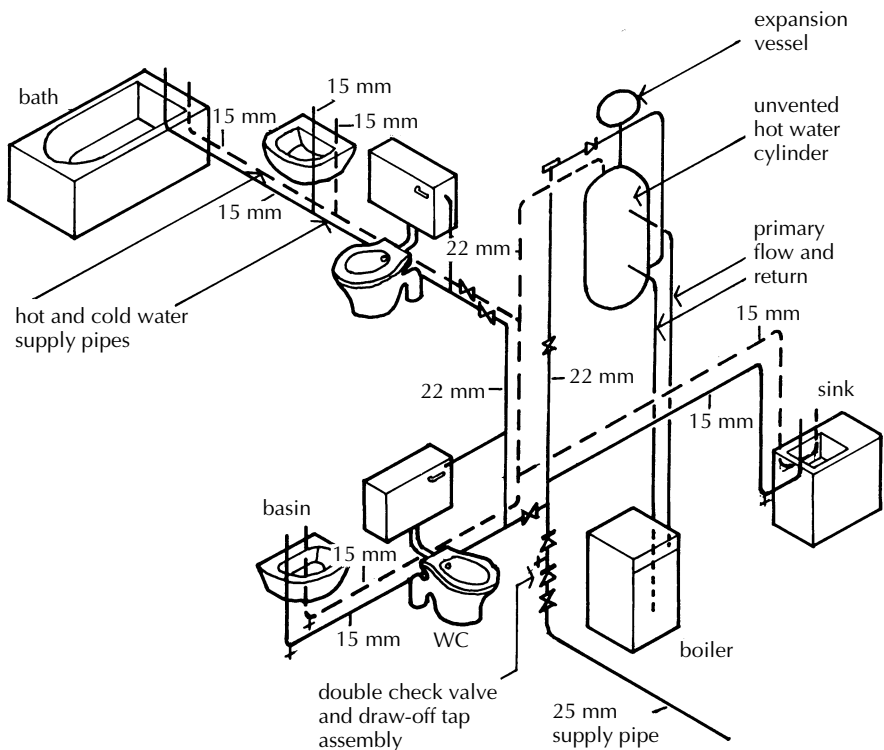
Figure 12.13   Unvented hot water supply.
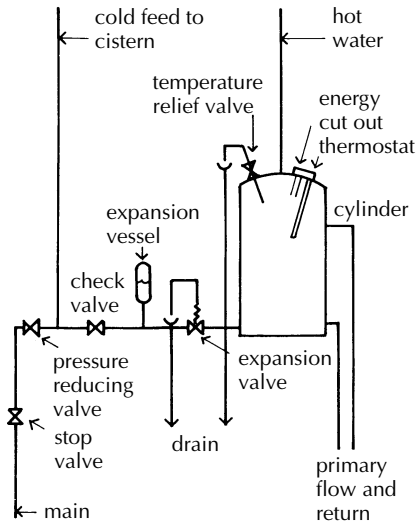
Figure 12.14   Diagram of low pressure unvented hot water system.

accommodated by the vented expansion pipe that will discharge an excess of expansion water to the cistern, and in the unvented system, expansion of hot water is relieved by an expansion vessel which contains a cushion of gas or air sufficient to take up the expansion by compression of the gas. The advantages of the unvented over the vented system lie in the improved flow rates from showers and taps, reduction in noise caused by the filling of storage cisterns, and virtually no risk of frost damage. The saving in eliminating the cistern, feed and expansion pipes is offset by the additional cost of the expansion vessel and temperature and expansion control valves, and the necessary, comparatively frequent, maintenance of these controls.

Figure 12.14 illustrates a low pressure unvented hot water cylinder. The pressure-reducing valve is fitted to the feed pipe where low pressure systems are used and is provided to reduce mains pressure to a level that the cylinder can safely withstand. Where high pressure systems are used and the cylinder is designed to stand high pressure, the pressure relief valve is omitted.

Expansion vessel
An expansion vessel is a sealed container in which a flexible diaphragm separates water from the cylinder and the air or gas, which the sealed vessel contains. As the water in the cylinder heats, it will expand against the diaphragm, compress the air and gas and so relieve the water expansion. In this way the expansion vessel acts in the same way as a vented expansion pipe to indirect systems. The pressure relief, or reducing valve, is a safety device against the expansion vessel being unable to take up the whole of the expansion of heated
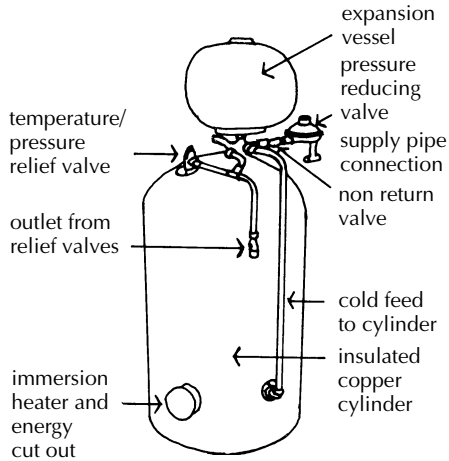
Figure 12.15   Unvented hot water storage cylinder.

water. For control against overheating there is a thermostat on the immersion heater and also a temperature limiting cut-out that operates on the electricity supply, and a temperature operated relief valve to discharge if the other controls fail. Figure 12.15 is an illustration of an unvented copper indirect cylinder prepared ready for installation as a packaged unit complete with factory applied insulation, expansion vessel and the necessary valves and controls.

Hot water supply pipework

The hot water supply pipework is run from the top of the cylinder with horizontal branches to the hot water outlets to fittings on each floor. Stop valves and draw-off taps are fitted to control and drain the pipe system as necessary for maintenance and repair.

Pipes (tubulars) for water supply

Until the middle of the twentieth century it was common to use lead for water supply pipework. The increase in the cost of lead following the Second World War resulted in the use of galvanised mild steel tubes and, later, of light-gauge copper tubes. Minute quantities of lead may be leached from lead pipes used for water supplies. These small amounts of lead may in time be sufficiently toxic, particularly to the young, to be a serious hazard to health. The Water Supply Regulations prohibit the use of lead for either new or replacement pipework for water supply. The Regulations also prohibit the use of lead solders for joining copper pipes, and so tin/silver solders are accepted. Lead pipework may be found when working on existing buildings and should be replaced with a suitable material. The materials used presently for pipework for water supplies are copper, galvanised mild steel and plastic.
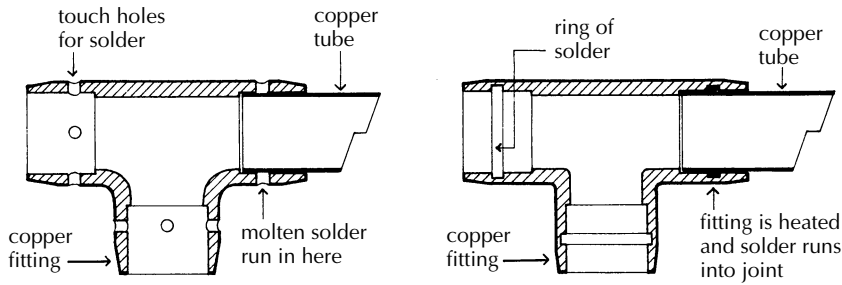
Figure 12.16   Soft solder capillary fittings.

Copper pipe (copper tubular)

The comparatively high strength of copper facilitates the use of thin-walled light-gauge pipes or tubes for most hot and cold water services. The ductility of copper facilitates cold bending, the thin walls make for a lightweight material and the smooth surface of the pipe provides low resistance to the flow of water. Light gauge copper tube, size 6 to 159 mm (outside diameter) is manufactured; the sizes most used in buildings are 12, 15, 18, 22, 28, 35, 42 and 54 mm.

Jointing

Copper pipes are joined with capillary or compression joints and welding, for the larger bore pipe for drains above ground where the pipework is prefabricated in the plumber's shop.

Capillary joint

A capillary joint is made by fitting plain ends of pipe into a shouldered brass socket. Molten solder is then run into the joint, or internal solder is melted by application of heat. Pipe ends and fittings must be clean; otherwise the solder will not adhere firmly to the pipe and socket. Figure 12.16 illustrates typical capillary joints. This is a compact, neat joint. Capillary joints are used for most small bore pipework, particularly where there are a lot of joints.

Compression joint

Compression fittings are either non-manipulative or manipulative. With the former, plain pipe ends are gripped by pressure from shaped copper rings; in the latter the ends of the pipes are shaped to the fitting, as illustrated in Figure 12.17. The manipulative fitting is used for long pipe runs and where pipework is not readily accessible, as the shaped pipe ends are more firmly secured than with the non-manipulative or capillary joint. Compression joints are often combined with capillary joints at the ends of pipe runs to facilitate repairs or alterations, because of the ease of disconnecting these joints. The thin walled copper tubulars used for water services have poor mechanical strength in supporting the weight of a filled pipe. The pipework should, therefore, be
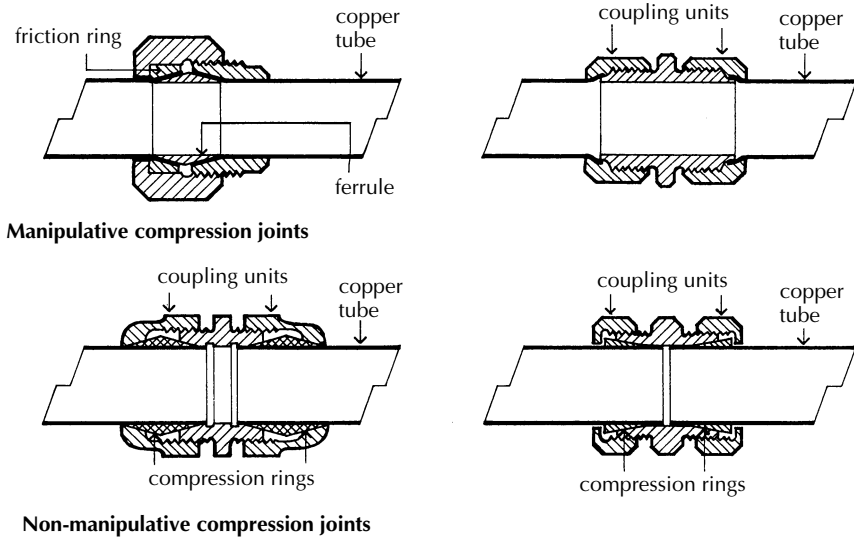
Figure 12.17   Compression joints.

supported at comparatively close intervals by pipe clips screwed to plugs in walls. The pipe clips, illustrated in Figure 12.18, should be fixed at intervals of from 1.5 to 3 m horizontally and 2 to 3 m vertically, depending on the size of the pipe.

Galvanised mild steel (low carbon steel)

Galvanised mild steel tubulars are used for service, supply and distributing pipework, 40 mm bore and over, particularly where there are long straight runs of pipework, because of the economy of material and labour. For water services, tubulars should be galvanised to resist corrosion. The pipe ends are threaded and the joint made with sockets, nipples or long screws, unions or fittings as illustrated in Figure 12.19. Pipes are supported at intervals of from 2.5 to 3 m.
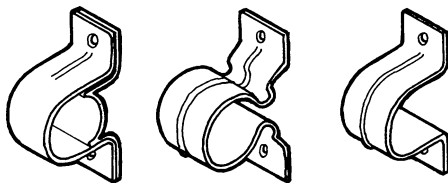
Figure 12.18   Copper fixing clips.
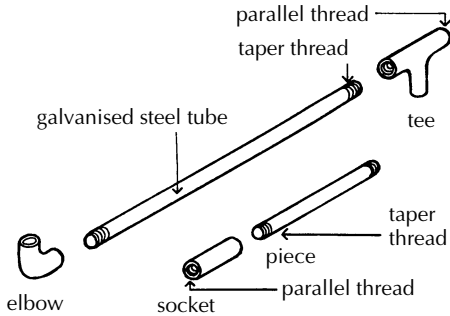
Figure 12.19   Galvanised steel pipe.

Plastic pipe or tube

Polythene and unplasticised PVC (polyvinyl chloride) tube is used respectively for use underground and above ground for water services. Polythene (polyethylene) is flexible and used for water services underground, while the more rigid PVC is used for services above ground. Both materials are lightweight, cheap, tough, do not corrode and are easily joined. These materials soften at comparatively low temperatures and are used principally for cold water services and drains above and below ground. The pipes are manufactured in sizes from 17 to 609 mm, the sizes most used being 21.2, 26.6, 33.4, 42.1 and 60.2 mm (outside diameter). uPVC and ABS (acrylonitrile butadine styrene) pipes are used primarily for waste pipes. Polythene tube is jointed with gunmetal fittings as illustrated in Figure 12.20. A copper compression ring is fitted into the pipe ends to prevent the wall of the pipe ends collapsing as the coupling is connected by tightening the nut. This type of joint is used to withstand high pressures, as in mains pressure supply pipework.

Solvent welded joint

Solvent weld cement is applied to the ends of the pipes to be joined and the ends of the pipes are fitted into the socket or other fitting (Figure 12.20). The solvent cement dissolves the surfaces of the pipe end and fitting so that as the solvent hardens it welds the joined plastic surfaces together. The joint will set in 5 to 10 minutes and require 12 to 24 hours to become fully hardened. This type of joint is commonly used with uPVC pipework, such as low pressure distribution pipework and more particularly waste branch pipes. Pipe runs in plastic are supported by clips at 225 to 500 mm horizontally and 350 to 900 mm vertically.

Insulation

Cold and hot water supply and distributing pipes should be fixed inside buildings, preferably away from external walls to avoid the possibility of water freezing, expanding and rupturing pipes and joints. Where pipes are run inside
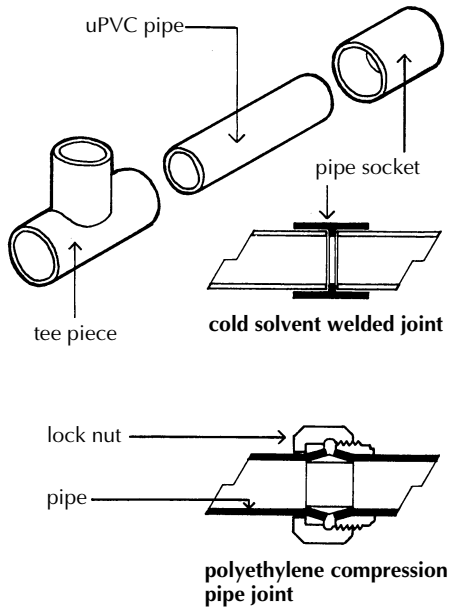
Figure 12.20   PVC pipe.

rooftop tank rooms and in unheated roof spaces, they should be insulated. Similarly, roof-level and roof-space storage cisterns should be fitted with an insulation lining to all sides, the base, and to the top of the cisterns.

Valves and taps

The two general terms used to describe fittings designed to regulate or shut the flow of water along a pipeline, are valve and cock. A valve is a fitting that can be adjusted either to cause a gradual restriction in flow or a cessation of flow. For this reason valves are also known as stop valves. A cock (or stop cock) is a fitting that consists of a solid cylindrical plug, fixed with its long axis at right angles to flow. When shut the plug fills the pipe line. A 90°, quarter turn, of the plug brings a round port or hole in the plug into line with the flow, and so opens the plug. There is little control of flow with a plug that is designed to be either shut or open.

Valves

The two valves in common use are the globe valve and the gate valve (see Figure 12.21). Globe valves control or shut flow through a disc that is lowered slowly by turning a screwdown spindle to a seating (they are also described as screw down valves) and are commonly used in high pressure and hot water pipework. A gate valve operates by raising or lowering a metal gate into, or out of, the line of the pipework as the spindle is screwed down or up. This
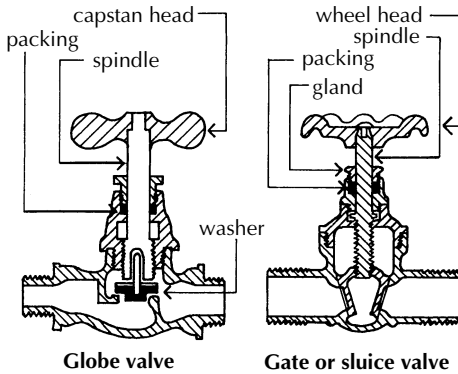
Figure 12.21   Valves.

valve is sometimes referred to as a fullway gate valve as when it is fully open it does not restrict flow along the pipeline, unlike the globe valve. For this reason the gate valve is used where there is low pressure flow in the pipeline, such as that from cistern feed systems.

Taps

The word tap is used in the sense of drawing from or tapping into, as these fittings are designed to draw hot or cold water from the pipework. They are sometimes described as draw-off taps. There are three types of draw-off tap: the bib tap, the pillar tap (including mixer taps which mix hot and cold water) and the draw-off tap, which is used to draw off water to drain pipe systems.

The bib tap (Figure 12.22) operates in the same way as a globe valve through a disc which is screwed down to close and up to open, except that the tap is at the end of a vertical pipeline to open to discharge water. A washer fixed to
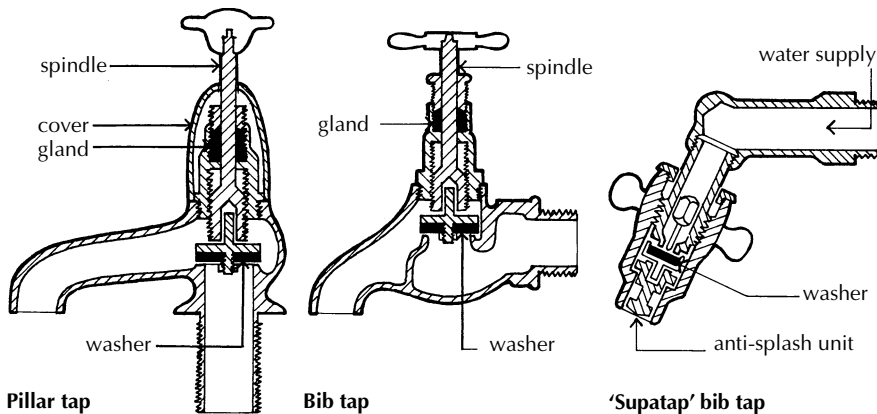
Figure 12.22   Taps.
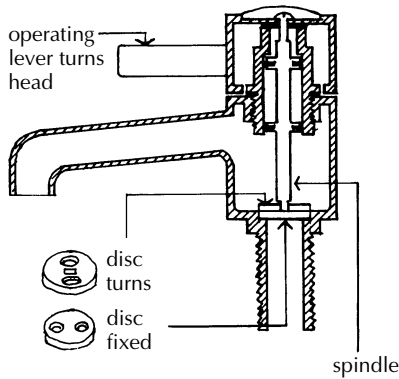
Figure 12.23   Quarter turn tap.

the base of the disc seals the tap when shut. A 'draw-off' tap is similar to a bib tap except that it is operated by a loose wheel or capstan head and the outlet discharge is serrated to take a hose connection.

The pillar tap (Figure 12.22) is designed to be fitted to the bath, basin or sink it serves, with the supply pipe connected vertically to the base of the tap. The tap operates in the same way as a bib tap, through a screw down spindle, which opens or closes a washer.

The 'supatap', illustrated in Figure 12.22 is designed so that the washer may be replaced without turning off the water supply, through an automatic closing valve that interrupts the supply.

Quarter turn taps

Many modern taps use a system of ceramic discs to open and close the supply. The lower disc is fixed and the top disc can be turned through 90°. When the two ports or holes in the top disc coincide with those in the bottom fixed disc, the water flows. A lever, when turned or depressed, operates a spindle to effect the necessary quarter turn to open the tap for water to flow. The advantage of these taps is that the polished ceramic discs will last as long as the tap itself without need of replacement. The simple operation of these taps makes it possible to design plain, elegant taps that consist of a plain steel cylinder on which a lever operates to open and shut the tap and can be used to operate a hot and cold water mixer. Figure 12.23 is an illustration of a quarter turn tap with ceramic disc washers.

12.2 Sanitary appliances

Sanitary appliances, sometimes termed sanitary fittings, include all fixed appliances in which water is used either for flushing foul matter away or in which water is used for cleaning, culinary and drinking purposes. The former,

termed soil appliances, include WCs and urinals, the discharge from which is described as soil, soiled or foul water. The second type, termed waste appliances, includes wash-basins, baths, showers, sinks and bidets, the discharge from which is described as waste water.

Functional requirements

The primary functional requirements of sanitary appliances are:

❑ The safe and hygienic disposal of waste
❑ Durable and easy to clean/maintain

Soil appliances

WC suite

WCs are sold as a matched set of WC pan, seat, flushing appliance and any necessary flush pipe, which together are described as a WC suite. The letters WC stand for water closet, the word closet referring to the small room, enclosure or closet in which the early soiled water pans were enclosed.

A WC pan is a ceramic or metal bowl to take solid and liquid excrement, with an inlet for flushing and a trapped outlet. The seat is secured to the back of the pan. The flushing appliance is a cistern designed to discharge water rapidly into the pan through a flush pipe, for cleaning and disposal of contents. The flushing cistern may be fixed high above, near to or closely coupled to the pan, the three arrangements being described as high-level, low-level (low-down) or close-coupled WC suites, as illustrated in Figure 12.24.
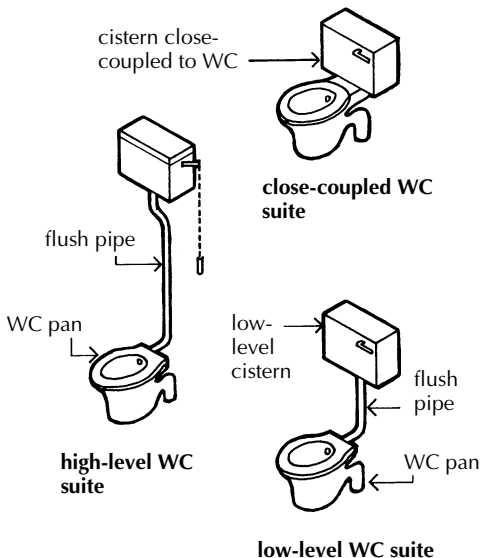
Figure 12.24   WC Suites.
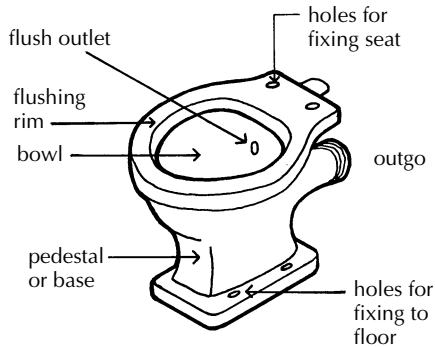
Figure 12.25   Pedestal WC pan.

Most WC pans are of the pedestal type, the base or pedestal being made integral with the pan, which is secured to the floor with screws through holes in the pedestal base to fixing plugs in solid floors or directly to timber floors (Figure 12.25). The flushing rim is designed to spread the water, which discharges through the flush outlet, around the pan to wash down the sides of the bowl. Most WC pans are made of vitreous china, which, after firing, has an impermeable body and a hard, smooth, glazed finish that is readily cleaned. The glazed finish to pans is generally white but the pan may be finished in various colour glazes. The flushing cistern body and cover to close-coupled WC suites is also made of vitreous china. Stainless steel is often used in public areas as a more durable alternative to vitreous china. WC pans have integral traps to contain a water seal against odours from the drain pipes or drains.

The washdown and the siphonic pan are distinguished by the operation of the flush water in cleansing and discharging the contents of the pan. In the washdown pan (Figure 12.26) the flush water runs around the rim to wash down the bowl and then overturns the water seal to discharge the contents. In the siphonic pan (Figures 12.27 and 12.28) the flush water washes the sides of the bowl and also causes a water trap or traps to overturn and create a siphonic action which discharges the contents. The purpose of this arrangement is to effect a comparatively quiet flush and discharge of contents.

Discharge outgo
The majority of washdown WC pans are made with an outgo that is near horizontal, with a small slope down as illustrated in Figure 12.26. This standard arrangement is used for simplicity in production and consequent economy. This type of outgo, described as a P trap outgo (Figure 12.29), suits most situations as drain fittings are available to provide a connection to soil pipes relative to the position of the WC. In some situations the WC pan may discharge to a drain below the floor level and it is convenient to have a vertical outgo. This

Section

Plan
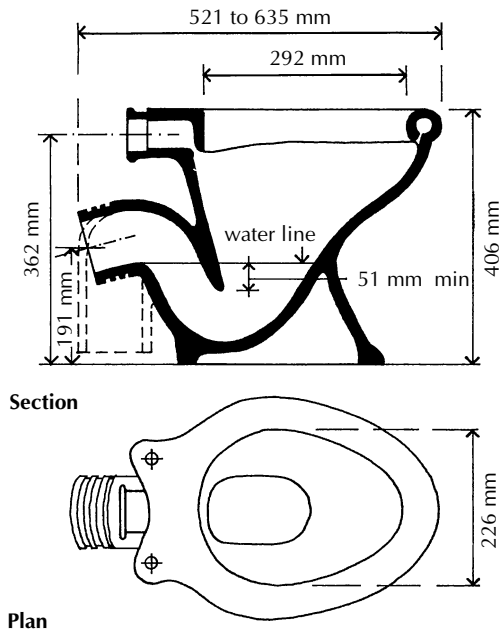
Figure 12.26   Wash down WC pan.
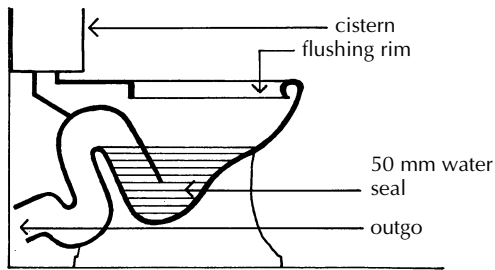
Figure 12.27   Single seal siphon WC pan.
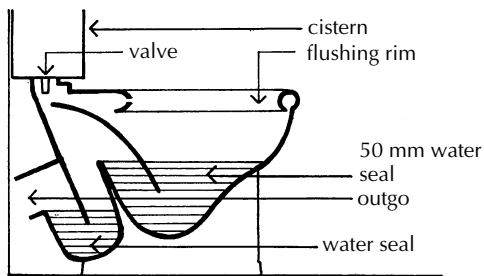
Figure 12.28   Double seal siphonic WC pan.

S trap outgo   P trap outgo
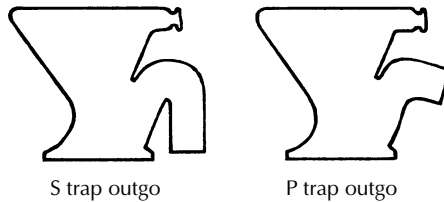
Figure 12.29   WC pan outgoes.

type of outgo is described as an S trap (Figure 12.29. P traps and S traps are so named for their sectional similarity to the letters. Where a WC pan has to discharge to one side of its position, rather than straight back through a wall, it may be convenient to have a left hand or right hand outgo rather than several unsightly drain fittings. This somewhat exceptional arrangement is illustrated in Figure 12.30. The hand, either right or left, is indicated by facing the front of the pan.

The connection of the outgo of a ceramic pan to the branch drain pipe is a common site of leaks because of the difficulty of maintaining a watertight joint and making some allowance for inevitable movement between the pan and the drain branch. The traditional joint between the spigot, open pipe, end of the WC outgo and a cast iron drain branch is a cement joint as illustrated in Figure 12.31. The majority of soil pipes and branches now used are run in plastic pipe sections. The connection of the ceramic pan outgo to the plastic branch is effected by a plastic connector which is solvent welded to the soil pipe branch and whose socket end fits around the pan spigot. The seal is made with a tight fitting plastic adaptor that fits around the pan spigot outgo and adaptor as shown in Figure 12.32.

Flushing cisterns

In the average household, up to 40% of total water consumption is by the use of WC flushing cisterns, and consecutive water Acts have aimed at reducing the amount of water used with each flush. Under the current Act no flushing device should exceed 6 litres in a single flush and, where the flushing device is designed to give the option of a reduced flush, this should consume at least one-third less water, i.e. a maximum of 4 litres of water per flush. Alternatives

Right hand outgo   Left hand outgo
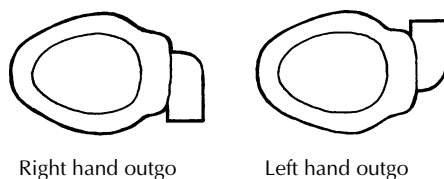
Figure 12.30   WC pan outgoes.
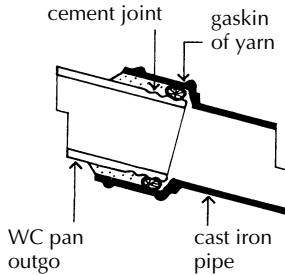
Figure 12.31   WC to cast iron pipe.

to flushing treated water are systems designed to use recycled water, 'grey water' (e.g. rainwater collected from the roof and stored for use) or compost toilets, which are based on a dry system of disposal.

Small bore macerator sanitary system
The Building Regulations permit the use of small bore pipe discharges from WCs. They have been used in Europe for many years and their use depends on the macerator and pump fitted to the outlet of WC pans. The electrically powered macerator and pump comes into operation as the normal flush of a WC pan, by a conventional cistern, fills the pan. A macerator is a rotary shredder that reduces solid matter to pulp, which is, with the flush water, then pumped along a small (18 to 22 mm) pipe to the discharge stack. The macerator and pump unit fits conveniently behind a WC pan (Figure 12.33). The unit is connected to the horizontal outlet of a BS 5503 pan and a small bore outlet pipe. The macerator and pump are connected to a fixed, fused electrical outlet.

The particular advantage of the small bore system is in fitting a WC in either an existing or a new building some distance from the nearest foul water drainage stack, with a small bore (18 to 22 mm) pipe that can be run in
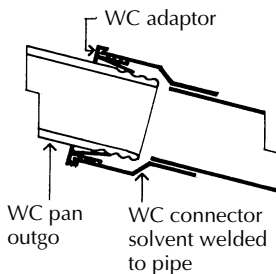
Figure 12.32   WC to plastic pipe.
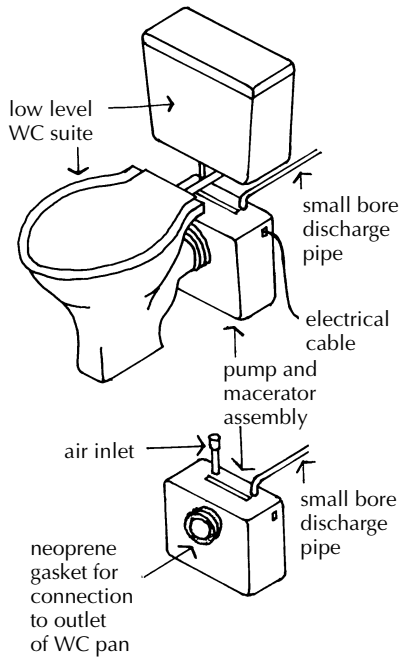
Figure 12.33   Macerator unit for small bore discharge for WCs.

floors or can be easily boxed in. In addition, because of the pumped discharge, the small bore branch discharge pipe can carry the discharge for up to 20 m with a minimum fall of 1 in 180 and can also pump the discharge vertically up to 4 m, with a reduced horizontal limit, which is of considerable advantage in fitting WCs in basements below drain levels. The macerator and pump unit can also be used to boost the discharge from other fittings such as baths, basins, sinks, bidets and urinals along small bore runs, with a minimum fall, and over considerable runs not suited to normal gravity discharge. The small bore discharge system is not a substitute for the normal short run branch discharge pipe system for fittings grouped closely around a vertical foul water drainage system, because of the additional cost of the macerator and pump unit and need for frequent periodic maintenance of the unit.

Urinals
The three types of urinal in general use are the stall urinal, slab urinal and bowl urinal as illustrated in Figure 12.34. Materials used are stoneware with salt glazed or white glazed finish, or stainless steel, which tends to be more durable in use. Consideration should be given to ease of cleaning and maintenance and resistance to vandalism.
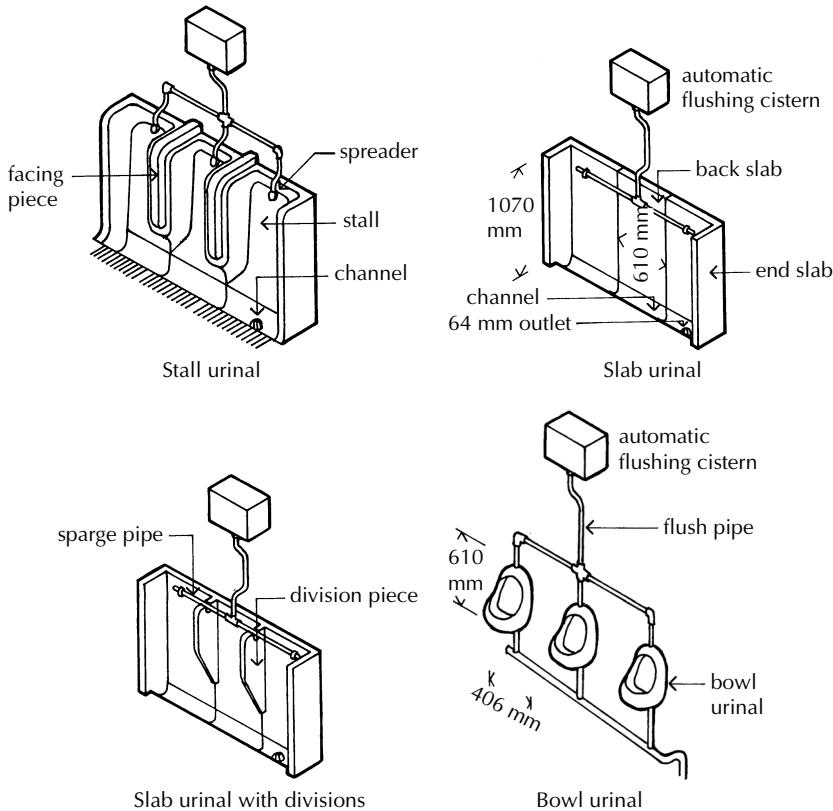
Figure 12.34   Stall, slab and bowl urinals.

Urinals are flushed by automatic flushing cisterns fixed above the urinal and discharging through a flush pipe, spreaders or sparge pipe. The automatic flushing cistern must not use more than 10 litres of water per hour for a single urinal, or 7.5 litres per hour per urinal bowl, and is triggered by a sensor (thus only flushing when necessary). One outlet to the trap and branch discharge pipe is used for up to six stalls or slab units, the outlet being in the channel to the slab or in the channel of one of the stall units. The outlet, 40 mm minimum diameter, is covered with a domed, gun metal grating and the outlet connected to a trap and waste. To accommodate the channel of urinals in a floor, a step is often formed. Figure 12.35 shows a typical urinal slab with channel, trap, and waste.

Waste water appliances

Wash basins
Wash basins, designed for washing the upper part of the body, are sup-ported by wall brackets or by a pedestal secured to the floor, as shown in
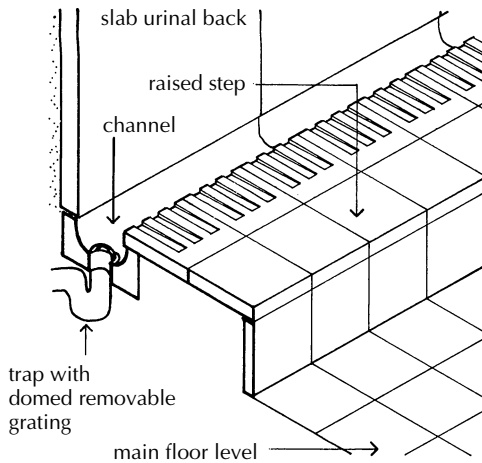
Figure 12.35   Urinal step.

Figure 12.36. The standard wash basin consists of a bowl, soap tray, outlet, water overflow connected to the outlet, and holes for fixing taps. The wall-mounted basin is fixed on brackets screwed to plugs in the wall. The pedestal basin consists of a basin and a separate vitreous china pedestal that is screwed to the floor and on which the basin is mounted. The purpose of the pedestal is to hide the trap, waste and hot and cold service pipes. Either the whole or a large part of the weight of the basin is supported by the pedestal. A resilient pad is fitted between the bottom of the basin and the top of the pedestal as the two separately made fittings rarely make a close fit. The majority of wash basins are made of vitreous china, although stainless steel is a popular alternative.

Hot and cold taps, connected to 12 or 15 mm hot and cold distributing or supply pipes are fixed to wash basins. An overflow is usually formed during

Wash basin fixed
on wall brackets

Wash basin on
pedestal
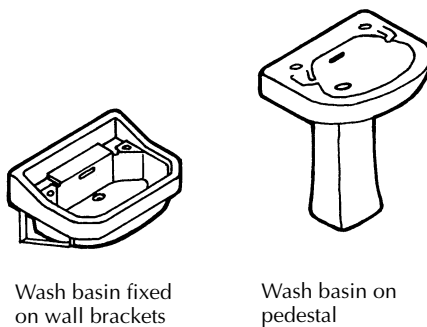
Figure 12.36   Wash basins.
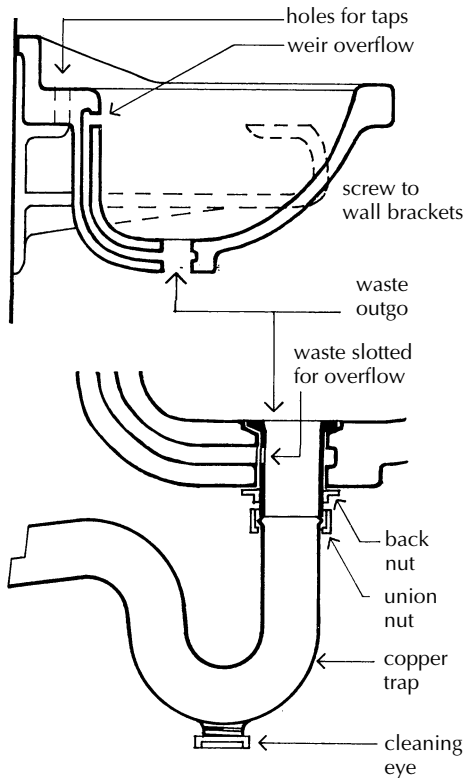
Figure 12.37   Wash basin waste and trap.

the manufacture of basins, which consists of a hole in the top of the basin, which can drain to the outlet, as shown in Figure 12.37.

A waste outgo, with slot to drain the weir overflow, is formed in the basin. A waste is fitted to the outgo, bedded in setting compound and secured with a back nut, as shown in Figure 12.37. A copper or plastic P trap with 75 mm water seal is then connected to the waste outgo and the copper or plastic waste pipe.

Baths

A wide range of styles and sizes of baths are available, with materials used ranging from porcelain-enamelled cast iron, enamelled pressed sheet steel, to plastic. Baths are fixed on adjustable feet against a wall or in a recess with side and end panels of pre-formed board, plastic or metal secured to wood or metal brackets or frames. The plaster or tile wall finish is brought down to the top of the bath rim. A 75 mm seal trap is fitted to the bath waste and connected to the 40 mm waste. An overflow pipe is connected to the bath and either run
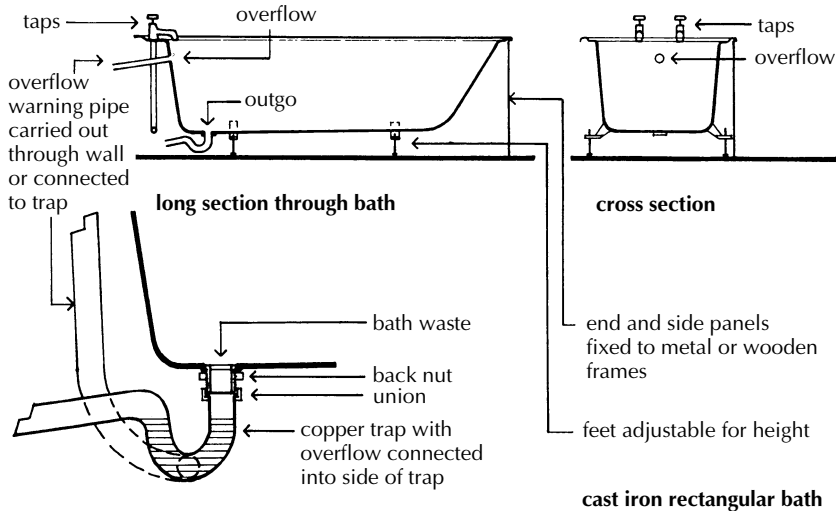
Figure 12.38   Plumbing to bath.

through an outside wall as an overflow warning pipe or connected to the bath outlet or trap, as illustrated in Figure 12.38.

The 18 mm cold and hot distributing or supply pipes are connected to either individual pillar taps, a mixer with taps or a shower fitting, or both, with an air gap between the outlet and spillover level of the bath, similar to that for basins. Where shower fittings are provided, the wall or walls over baths should be finished in some impermeable material such as tile, and a waterproof curtain be provided.

Showers
This consists of a shower tray of glazed ceramic, enamelled cast iron or plastic to collect and discharge water, with a fixed or hand-held shower head or rose and mixing valves. The shower is either fixed in a wall recess or may be a free standing cubicle. The walls around fixed showers are lined with some impermeable material such as tile, and the open side is fitted with a waterproof curtain or screen. Figure 12.39 shows some shower trays. The tray with a waste and no overflow is for use as a shower only. The tray with a waste plug and an overflow is for use either as a shower or a foot bath.

A shower compartment is often surrounded with an upstand curb or may be sunk into the floor to contain the shower water that would otherwise spill over the surrounding floor. The shower tray may be fixed on to or recessed into the floor. A 75 mm seal trap is fitted to the tray and connected to a 40 mm waste.

Bidets
A bidet consists of a glazed ceramic pedestal bowl, which is secured to the floor, usually backing on to a wall or partition. The shallow bowl has a flushing rim,
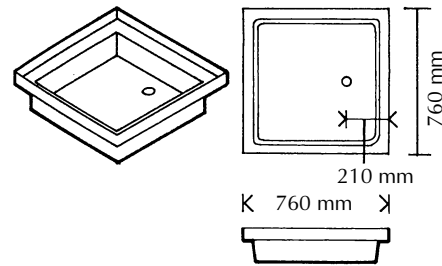
acrylic shower tray
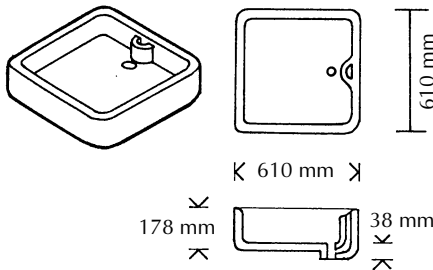
glazed fireclay shower tray

Figure 12.39   Shower trays.

a weir overflow connected to the waste and an inlet for a spray. An optional hand-held spray may be fitted to the hot and cold supply. The bidet operates through the discharge of water around the flushing rim, and a spray of water that rises from the bowl or a hand-held spray. The bowl may be filled with water and drained by the operation of a pop-up waste control. Figure 12.40 shows a bidet with a 75 mm trap from the waste outgo to a 40 mm waste pipe. As a precaution against the possibility of contamination of the mains supply
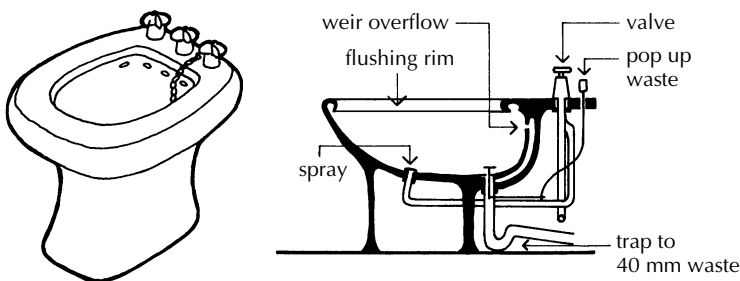
Figure 12.40   Bidet.
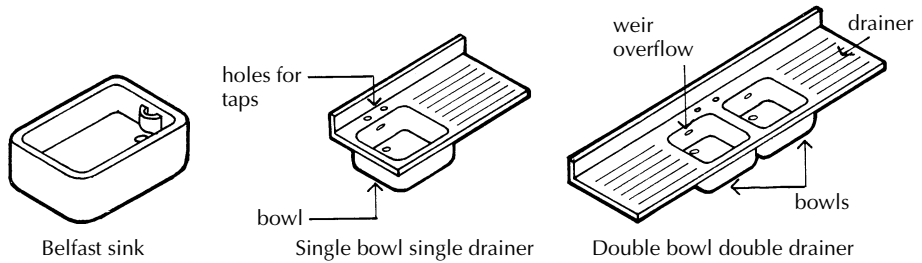
Figure 12.41   Range of sinks.

from a bidet, particularly through the submerged spray, a separate cistern feed to a bidet or other effective device to sprays and hand-held showers, such as double-check valve assemblies, is required.

Sinks
The traditional kitchen sink was made of glazed stoneware, usually white glazed inside the bowl and salt glazed outside, commonly known as Belfast sinks (Figure 12.41), fitted under natural teak draining boards. A range of stainless steel sinks, designed to fit into kitchen and utility units, are made with single bowl and drainer, and double bowl and double drainer (Figure 12.41). The sinks are finished in the natural colour of the stainless steel from which they are pressed. Most sinks have weir overflows connected to the waste outlet and are holed for fitting hot and cold taps or mixers. A 75 mm seal trap is connected to the sink waste, which is connected to a 40 mm copper, or plastic waste pipe. Because of the flat base of the bowl a sink waste is unlikely to run full bore and cause self-siphonage.

Washing machines, dishwashers and other appliances
All appliances should be economical in the use of water, and manufacturers now rate their appliances for water consumption, energy use, and noise, with 'A' being the best grade and provide typical consumption figures for typical cycles. Water fittings to appliances should be readily accessible to allow access for routine maintenance and replacement.

Waste traps

A trap or waste trap is a copper or plastic fitting formed as a bend in pipework to contain a seal of water as a barrier to odours rising from sanitary pipework and drains into rooms. The traps are formed as P or S traps to accommodate the position of the waste pipe relative to the sanitary fitting outlet. At the bottom of the trap is a cleaning eye, which can be unscrewed to clear blockages. Figure 12.42 shows P and S traps.
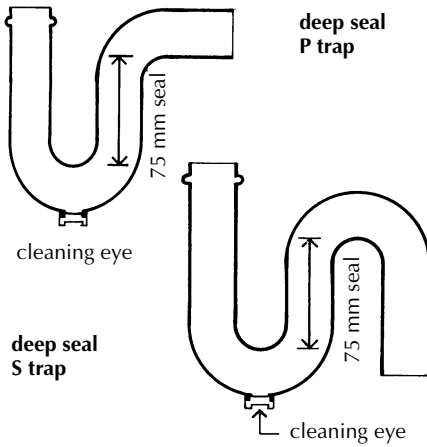
Figure 12.42   Deep seal S and P traps.

   The depth of the water seal is measured from the top of the first bend and the bottom of the second. The traps shown in Figure 12.42 are 75 mm deep seal traps, the depth of seal required for all sanitary fittings connected to single stack systems of drainage, except for WCs that have an integral 50 mm seal. The two piece trap in Figure 12.43 is used instead of the one piece trap because it can be adjusted to suit the position of the branch waste pipe relative to the appliance outgo, and can be uncoupled to clear blockages which are common with wash basins and sinks.

Sanitary pipework

From about the middle of the nineteenth century, due to improved pumping techniques, piped water increasingly extended above ground floor level, first to water closets and later to wash basins and baths. This improvement in sanitary and washing facilities was helped by the mass production of sanitary appliances. For economy the single stack system, illustrated in Figure 12.44, is used in both domestic and public buildings.
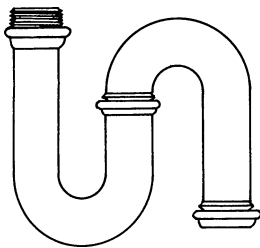
Figure 12.43   Two piece copper S trap.
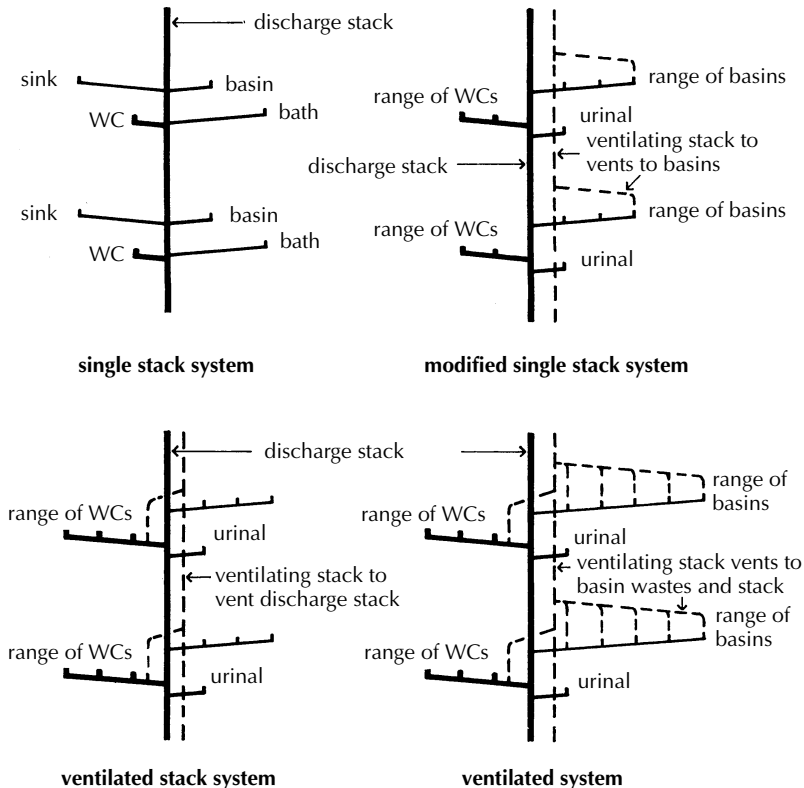
Figure 12.44   Single stack systems.

Ventilated system

Where pressure fluctuations in the stack and the branch wastes cannot be limited to prevent self-siphonage, induced siphonage and back pressure, for example in multi-storey buildings, a ventilated system is used, as shown in Figure 12.44. The single vertical pipe collecting discharges from all sanitary appliances is the discharge stack and the pipes from all appliances to the stack are discharge pipes. The single vertical ventilating pipe is the ventilating or vent stack and the branches from it to the discharge stack and discharge pipes are ventilating or vent pipes.

Figure 12.45 illustrates the application of the single stack system to a five floor residential building with one group of appliances on each floor. The discharge pipes are arranged within the limitations set out in Figure 12.46. The 100 mm single stack (shown in Figure 12.44) can also be used to take the discharge from two groups of appliances per floor for up to five floors. The single stack system of sanitary pipework was originally developed for houses. It has since been developed for use in multi-storey buildings, such as flats, where sanitary

Single stack for up to five floors

Single stack for up to 20 floors

Single stack for up to 25 floors
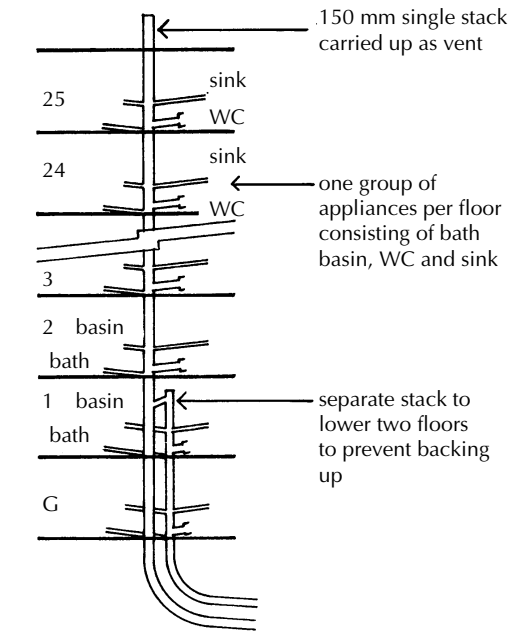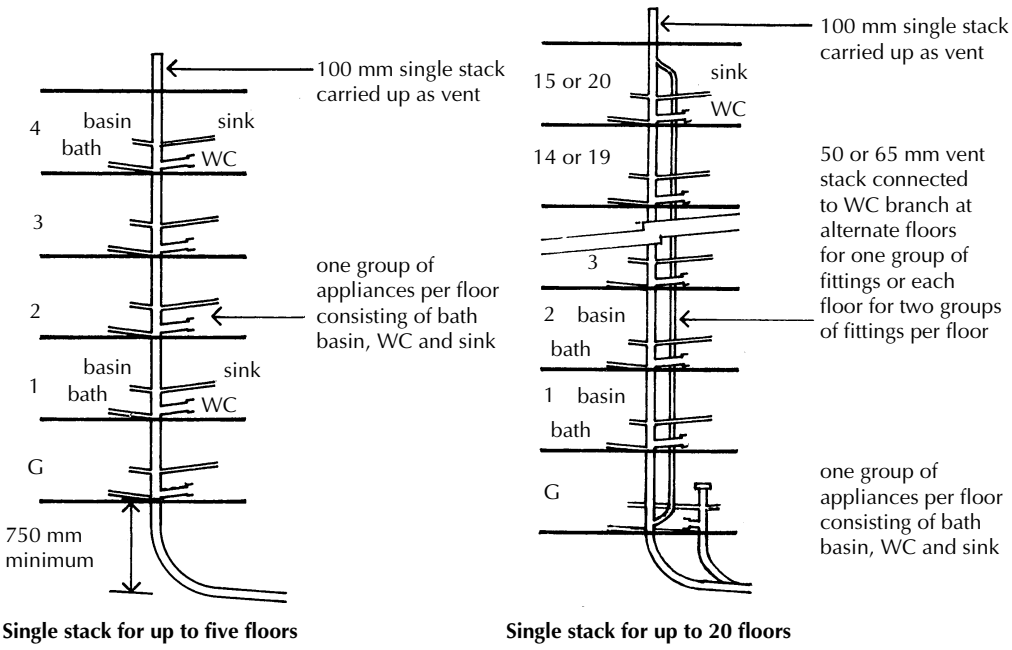
Figure 12.45   Applications of the single stack system.
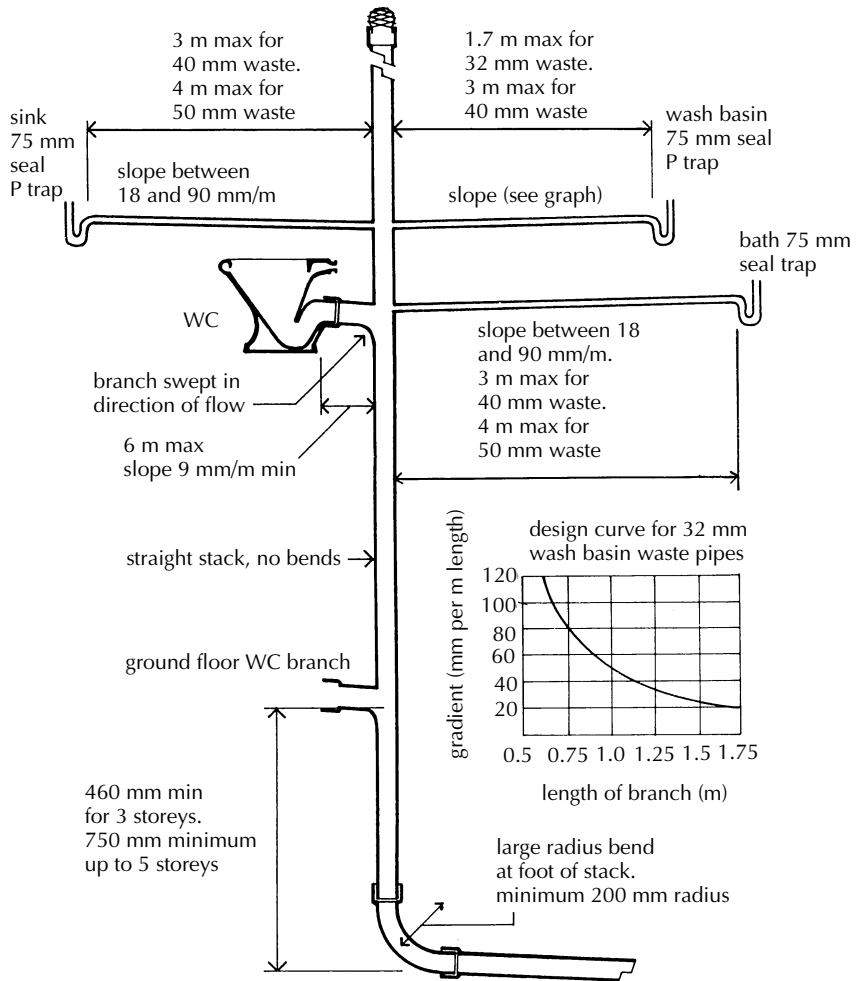
Figure 12.46   Single stack system.

fittings are closely grouped, floor over floor, so that short branch discharge pipes connect to a common single stack for economy in drain runs.

Traps

Where sanitary appliances discharge foul water to the sanitary pipework system there should be a water seal, provided by means of a trap, to prevent foul air from entering the building under working conditions. There is a water seal trap to each of the appliances. The minimum size and depth of water seal for these traps are set out in Table 12.1. Water closet pans have a water seal trap that is integral with the pan in the form of a single or double water seal (as illustrated in Figures 12.27 and 12.28).

Table 12.1   Minimum trap sizes and seal depths.

Appliance	Diameter of trap (mm)	Depth of seal (mm)
washbasin bidet	32	75
sink bath shower food waste disposal unit urinal bowl	40	75
WC pan (siphonic only)	75	50

Baths, bidets, sinks and wash basins have a trap that is fitted to the appliance and connected to the branch discharge pipe. To facilitate clearing blockages there should be a cleaning eye or the trap should be removable, as shown in Figure 12.42. To prevent the water seal in traps being broken by the pressures that can develop in a sanitary pipe system, the length and gradient of branch discharge pipes should be limited to those set out in Figure 12.46, or a system of ventilating pipes should be used.

Branch pipes
The discharge of foul water from sanitary appliances is carried to the vertical discharge stack by branch pipes, as shown in Figure 12.46. All branch discharge pipes should discharge into a discharge stack except those to appliances on the ground floor. Ground floor sinks, baths and wash basins may discharge to a gully, and WCs, bidets and urinals to a drain. A branch pipe from a ground floor WC should only discharge directly to a drain if the drop is less than 1.5 m, as shown in Figure 12.47. A branch pipe should not discharge into a stack lower than 450 mm above the invert of the tail of the bend at the foot of the
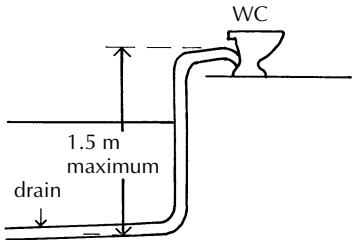
Figure 12.47   Direct connection of ground floor WC to drain.
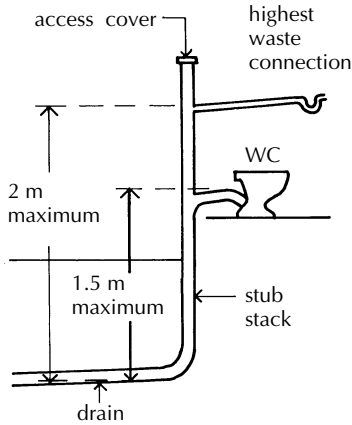
Figure 12.48   Stub stack ground floor appliances.

stack for single dwellings up to three storeys, and 750 mm for buildings up to five storeys high. The branch pipes from more than one ground floor appliance may discharge to an unvented stub stack, with the stub stack connected to a ventilated discharge stack or a drain, provided no branch is more than 2 m above the invert of the connection to the drain and branches from a closet more than 1.5 m from the crown of the closet trap, as shown in Figure 12.48. Branch pipes from waste water fittings such as sinks, baths and basins on the ground floor should discharge to a gully between the grating and the top level of the water seal. To avoid cross flow, small similar-sized connections not directly opposite should be offset by 110 mm on a 100 mm stack and 250 mm on a 150 mm stack. A waste water branch should not enter the stack within 200 mm below a WC connection as shown in Figure 12.49. Pipes serving single
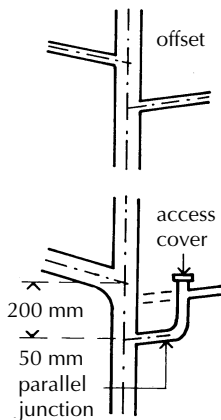
Figure 12.49   Branch connections to stack.

Table 12.2   Common branch discharge pipes (unvented).

Appliance	Max. number to be connected	Max. length of branch (m)	Min. size of pipe (mm)	Gradient limits (fall per m)	
				min (mm)	max (mm)
WCs	8	15	100	9	90
urinals: bowls	5	*	50	18	90
stalls	7	*	65	18	90
washbasins	4	4 (no bends)	50	18	45

* No limitation as regards venting but should be as short as possible.

appliances should be at least the same diameter as the appliance trap and should be the diameter shown in Table 12.2 if the trap serves more than one appliance and is unventilated.

Bends in branch pipes, which should be avoided if possible, should have a radius as large as possible and a centre line radius of at least 75 mm for pipes of 65 mm or less in diameter. Junctions on branch pipes should be made with a sweep of 25 mm radius or at an angle of 45°, and connections to the stack of branch pipes of 75 mm diameter or more should be made with a sweep of 50 mm minimum radius or 45°.

It is not necessary to provide ventilation to branch pipes whose length and slope is limited to the figures given in Figure 12.46, or to the common branch discharge pipes set out in Table 12.2. Where the length or slope is greater than these limits, the branch pipes should be ventilated by a branch ventilation pipe to external air, to a discharge stack or to a ventilating stack where the number of ventilating pipes and their distance to a discharge stack are large. Branch ventilating pipes should be connected to the discharge pipe within 300 mm of the trap and should not connect to the stack below the spillover level of the highest appliance served, as illustrated in Figure 12.50. Branch ventilating pipes to branch pipes serving one appliance should be 25 mm in diameter or
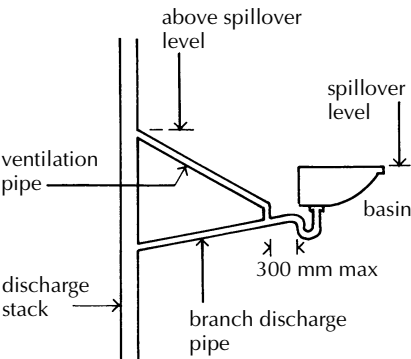
Figure 12.50   Branch ventilation pipe.

where the branch is longer than 15 m or has more than five bends, 32 mm in diameter. The discharge pipe is usually 100 mm in diameter.

Pipe materials

The materials used for discharge pipework above ground are cast iron, copper and plastics.

uPVC (unplasticised polyvinyl chloride) is the most commonly used material for discharge stack and branch pipe systems, because of its low cost, ease of cutting, speedily made joints and the range of fittings available. The pipework is secured with loose brackets that are nailed or screwed to plugs in walls. A variety of fittings are manufactured to suit the various branch waste connections for single stack systems of sanitary pipework. The plastic pipework is usually jointed by means of an elastomeric ring seal joint. The synthetic rubber ring forms an effective seal as it is compressed between the spigot and socket ends of the pipe as the spigot end is pushed into the socket. Connections of uPVC branch pipes to outlets of appliances are made with rubber compression rings that are hand tightened by a nut to a copper liner. Figure 12.51 is an illustration of a uPVC discharge stack to a house.
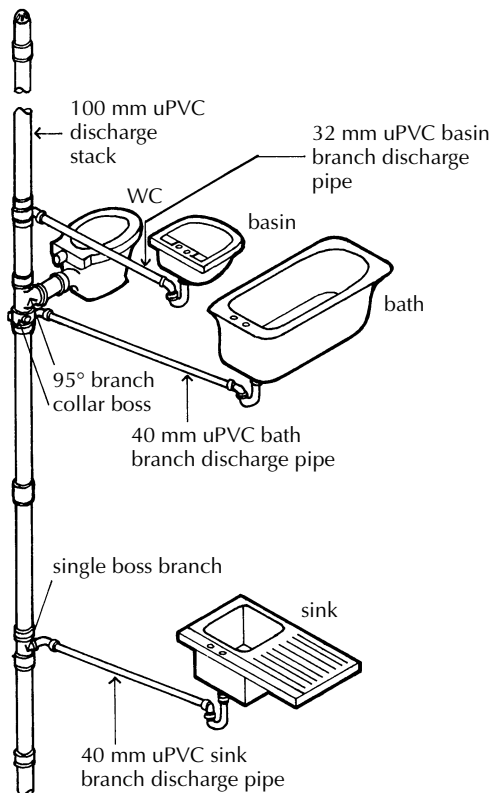
Figure 12.51   uPVC discharge stack and branches.
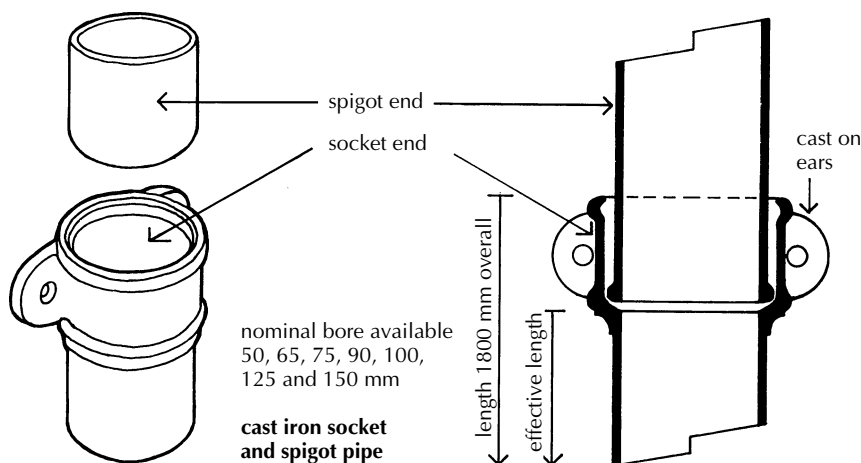
Figure 12.52   Cast iron pipes.

Cast iron pipes are used for discharge pipework where the strength and durability of the material and the wide range of fittings available justify the comparatively high initial cost. Where cast iron is used it is usual to run the discharge stack, WC discharge pipes and main branch pipes to ranges of fittings in cast iron, and discharge pipes from waste appliances in copper or plastic. In this way the strength and speed of fixing of cast iron is combined with the compact joints and ease of manipulation of copper or plastic pipe. The pipes and fittings are sand cast or spun with socket and spigot ends, as illustrated in Figure 12.52, and are given a protective coating of bitumen paint. A range of socket and spigot fittings, with or without bolted access doors, is provided. Joints are made with molten lead, which is caulked (rammed) into the joint that has been sealed with a gaskin of hemp, or with lead wool, caulked fibre or a rubber seal ring. Pipes and fittings are usually fixed by nailing through cast ears (lugs) to plugs in walls and floors.

Copper pipe (tubulars) with capillary or compression joints is used for discharge pipes to waste appliances because of the compact joints in this material, its ease of handling, and particularly for the facility of making bends in pipework run from appliances through walls to connect to discharge stacks.

Soundness test

Air test

The accepted method of testing the soundness of discharge stacks and pipes above ground is the air test. A sound pipe system will contain air under pressure for a few minutes as an indication of its capacity to contain the flow of liquid in conditions normal to a discharge pipe system. The air test is carried out

to the whole discharge pipework above ground in one operation or, where the pipework is extensive, in two or more operations. The traps of all sanitary appliances are filled with water and the open ends of pipes are sealed with expanding drain plugs or bag stoppers. Air is pumped into the pipework through the WC pan trap and the air pressure is measured in a U tube water gauge or manometer. A pressure equal to 38 mm water gauge should be maintained for at least three minutes if the pipework is sound. Figure 12.53 illustrates the equipment used for the air test. If the air pressure is not maintained for three minutes, leaks may be traced by spreading a soap solution around joints, with the pipework under air pressure; bubbles in the soap solution will indicate leaks. Alternatively, smoke is pumped into the pipework from a smoke machine and the escape of smoke will indicate leaks. Leaking joints are made good and the air test applied to test for soundness.
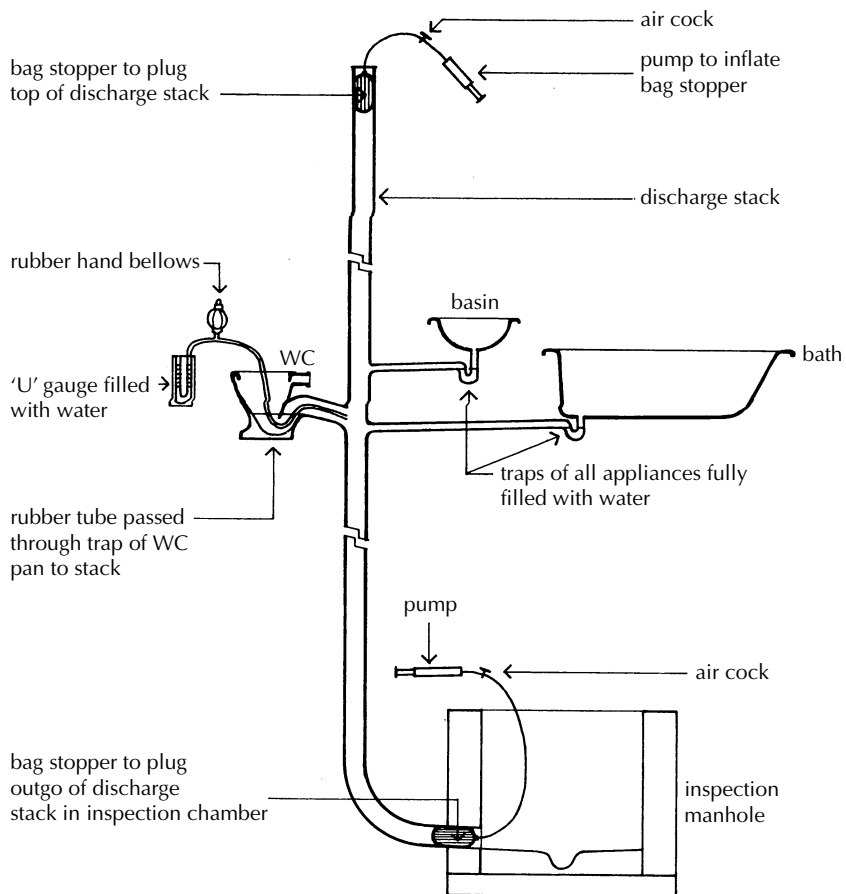
Figure 12.53   Air test for sealed discharge stack and branches.

In use test

To test the performance of a discharge pipe system in use, a group or groups of appliances are discharged simultaneously to cause conditions most likely to produce maximum pressure fluctuations. In buildings with up to nine appliances of each kind to a stack, the top-floor sink and wash basin are filled to overflowing and the plugs pulled simultaneous to a normal discharge of the top-floor WC. After this test a minimum of 25 mm water seal should be retained in every trap. With more than nine appliances of each kind to a stack, two or more WCs, basins and sinks are discharged simultaneously on the top floors for the performance in use test.

Pipe ducts

In large buildings all discharge pipework, together with hot and cold water services, are run internally in ducts for ease of access. Where there are internal bathrooms and WCs, to economise in pipework and to avoid overlarge ducts it is necessary to group sanitary appliances. Some compact groups of sanitary appliances and ducts and pipework are illustrated in Figure 12.54, which illustrates ducts to a bathroom with a WC and a separate bathroom and WC. Where there are two or more bathrooms and WCs on each floor of a multi-storey building, they will be grouped around a common duct.

Ventilation of internal WCs and bathrooms

Bathrooms and WCs are often sited internally in modern buildings, such as flats, and refurbishment schemes to maximise the use of space. It is necessary to provide means of extract ventilation to internal bathrooms and WCs, to dilute pollutants and moisture vapour in the air by air changes

Figure 12.54   Pipe ducts.

Horizontal outlet duct
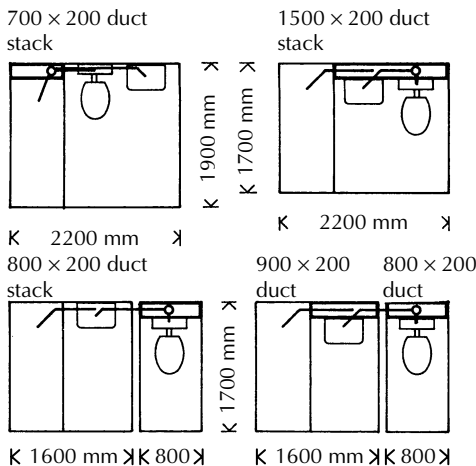
Horizontal inlet and outlet ducts
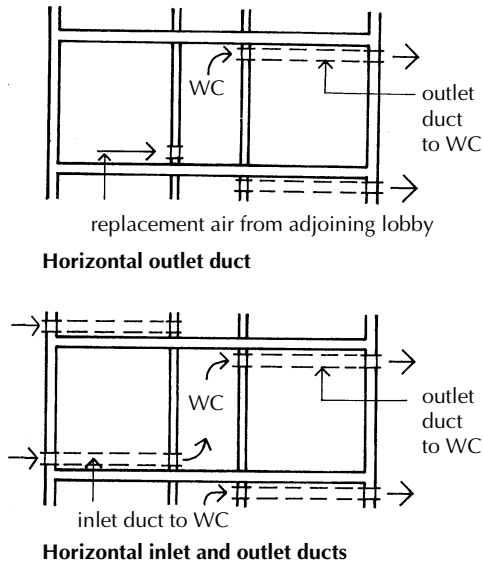
Figure 12.55   Ducts.

(Figure 12.55). Extract ventilation may be provided by mechanical extract of air or by passive stack ventilation. Passive stack ventilation is a ventilation system that uses ducts from the ceilings of rooms to terminals on the roof to operate through the natural stack effect of warm air rising, as in a chimney stack. Mechanical ventilation is effected by an electrically operated extract fan, designed to evacuate air through a duct to outside air (Figure 12.56). The
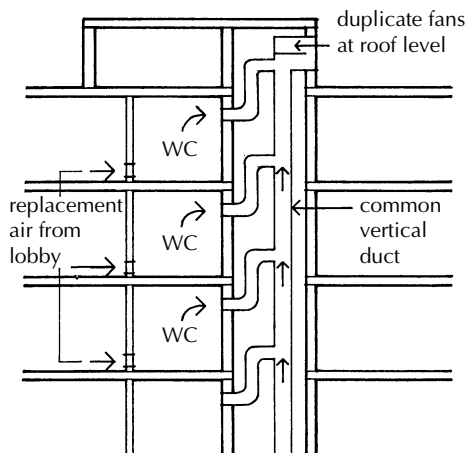
Figure 12.56   Mechanical extract system.

Building Regulations recommend mechanical extract ventilation of 60 litres a second for bathrooms and sanitary accommodation located internally. The extract fan should be controlled by the operation of the light switch to the room and have a 15 minutes overrun after the light is turned off. There should be a 10 mm gap under the door to bathrooms and sanitary accommodation, through which replacement air can enter.

12.3 Foul drainage

Functional requirements

The primary function of a foul drainage system is to facilitate the transfer of foul water and matter quickly, economically and safely from a building to the mains drainage or collecting vessel.

Drainage layout

The layout of foul drains depends on whether foul water and rainwater are discharged to a common drain system (combined) or to separate drain systems, which in turn depends on whether there is one sewer carrying both foul and rainwater or separate sewers for foul and rainwater. Foul drainage systems should be kept simple. Fittings that discharge foul water should be grouped together on each floor to economise on pipe runs; discharge pipe branches should run to a common waste stack and groups of fittings on each floor should be positioned one over the other to minimise pipework. Rainwater pipes from roof gutters and gullies to collect water from paved areas should also be positioned to simplify drain runs. Wherever practicable, changes of direction and gradient should be limited to minimise the number of access points.

Figure 12.57 is an illustration of combined and separate drainage systems to a small two-floor house. As the drains for foul water and rainwater will generally run across each other at some point, it is necessary to adjust the level or gradient (slope) of the drains to accommodate this.

A combined drainage system has to be ventilated throughout to conduct foul air discharge to the open air. In this system it is necessary to fit trapped gullies with a water seal. With separate systems of foul and rainwater drains it is necessary to fit trapped gullies only to the discharge of foul water fittings, where the discharge pipe does not serve as a ventilation pipe.

Foul water drainage systems should be ventilated by a flow of air, with a ventilating pipe to the head of each main drain and any branch drain that is more than 6 m long serving a single appliance or 12 m long serving a group of appliances. Ventilated discharge pipes such as discharge stacks, discharging directly to the drain, are commonly used for ventilation of drains.

Drain runs should be laid in straight lines wherever possible to encourage the free flow of discharge water by gravity, with gentle curves in drain runs only
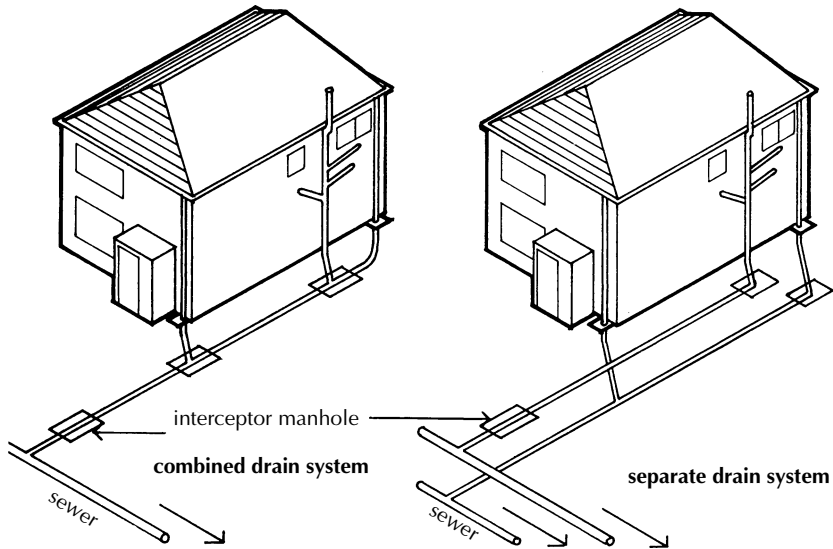
Figure 12.57   Combined and separate drain systems.

where straight runs are not practicable. Bends in drain runs should be limited to positions close to or inside inspection chambers and to the foot of discharge pipes and should have as large a radius as practicable. Where drain runs are near to or under a building, precautions should be taken to accommodate the effects of settlement without damage to the drain.

Drain pipes

Short, cylindrical, vitrified clay pipes have for centuries been used for drains underground. The joints between the pipes were made with puddled clay, either packed around the butt ends of adjacent pipes, packed into loose clay collars joining pipe lengths or packed into the socket end of one pipe around the spigot end of the next. Clay pipes generally failed by brittle fracture either across or along the pipe or around sockets, whereas pitch fibre pipes generally failed by being flattened without fracture. The different behaviour of clay and pitch fibre pipes under load prompted the current classification of pipes as rigid or flexible.

❑ Rigid pipes are those that fail by brittle fracture before they suffer appreciable deformation, and these include clay, concrete, cement and cast iron.
❑ Flexible pipes are those that suffer appreciable deformation before they fracture, and these include pitch fibre and uPVC.

   The deformation of flexible and rigid pipes has been controlled by the use of a granular bed, and limitations of load by the design of the trench and its backfilling.

Clay pipes

Clay pipes are mass produced in highly automated plants. The selected clays are ground to a fine powder and water is added for moulding. Simple fittings are formed by extrusion and the parts of junctions are extruded and then cut and joined by hand. The moulded clay pipes and fittings are then dried in kilns to encourage uniform loss of water, to avoid loss of shape, and then fired in continuous tunnel kilns. Pipes and fittings that are to be glazed have a ceramic glaze or slip sprayed on, or they are dipped in the slip before they enter the kiln.

The nominal bore (inside diameter) of clay pipes for drains is from 75 to 900 mm in increments of 25 mm between 75 and 250 mm, one increment of 50 mm to 300 mm and then increments of 75 mm from 300 to 900 mm, as illustrated in Figure 12.58. A wide range of more than 250 fittings is made for clay drains such as bends, junctions, channels and gullies, some of which are shown in Figure 12.59. The advantage of the clay pipe for drains is that the
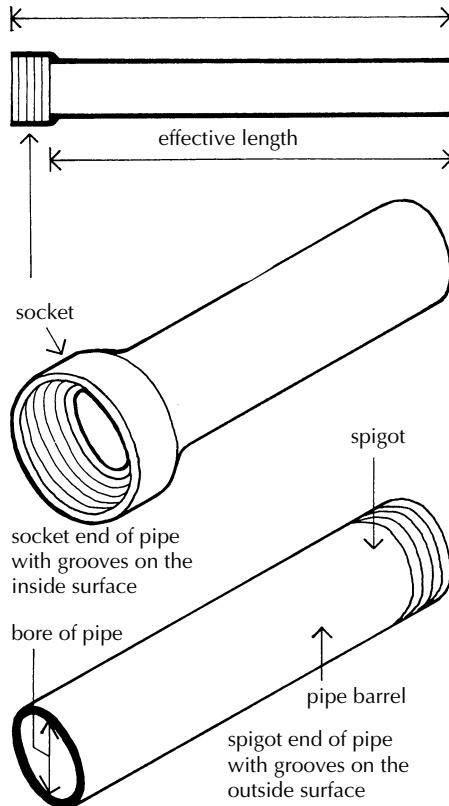
Figure 12.58   Clay drain pipes.
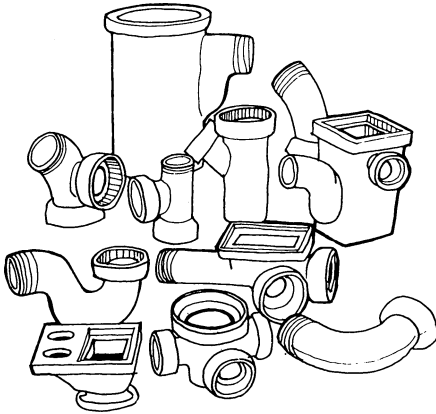
Figure 12.59   Clay drain pipe fittings.

comparatively short length of pipe and the wide range of fittings are adapt-
able both to the straightforward and the more complex drain layouts and the
pipes themselves are inert to all normal effluents.

Jointing
Flexible joints should be used with rigid clay drain pipes so that the drain
lines can accommodate earth movements under, around or over the pipeline,
within the joint. The flexible joint can be made in all weather conditions and,
once made and tested, the trench can be backfilled to protect the pipeline
from damage. There are two types of flexible joint in use: the socket joint for
socket and spigot pipes and the sleeve joint for plain-ended clay pipes. Typical
joints are shown in Figures 12.60 and 12.61. These flexible joint seals are made

sealing action achieved by
rubber gasket O ring
located in the groove in the
spigot

plastic fairings cast round inside
of socket and outside of spigot
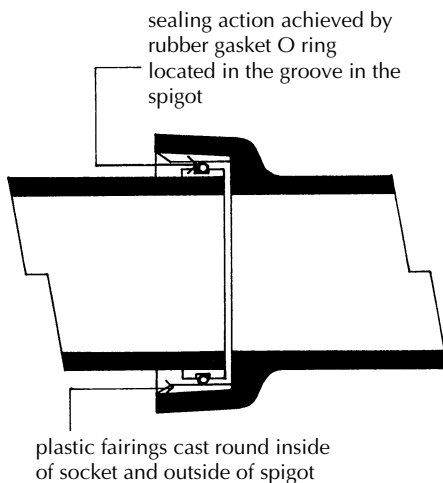
Figure 12.60   Section at junction of socket and spigot clay pipes.
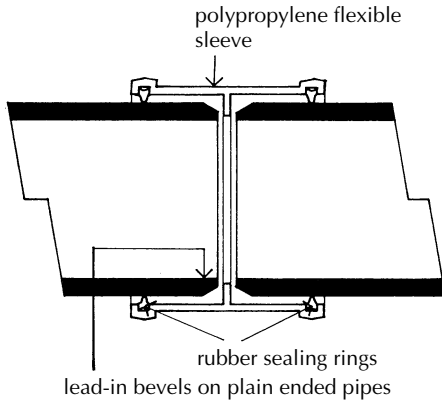
Figure 12.61   Section at junction of plain ended clay pipes showing flexible coupling.

from natural rubber, chloroprene rubber, butyl rubber or styrene-butadiene rubber. The flexible socket joint is made with plastic fairings cast on the spigot and socket ends of the pipe to provide a simple push fit joint. It suffers the disadvantages that the joint may be damaged in handling and cut pipe lengths present difficulties on site. The flexible coupling joint is made with a close fitting, flexible plastic sleeve with rubber sealing rings. The ends of the plain-ended pipes are bevelled to assist in forcing pipe ends into the sleeve to make a close watertight seal.

Cast iron pipes
Cast iron pipes are used for drains because of their superior strength where there is unstable or made up ground, in shallow trenches, under buildings, for drains suspended under floors of buildings, in heavily waterlogged ground and where sewage is under pressure from pumping. Cast iron and ductile iron pipes are made with socket and spigot ends or with plain ends, as shown in Figure 12.62. All pipes are hot dip coated with either a bituminous or tar coating inside and out. Pipes are manufactured with bores of 75, 100, 150 and 225 mm and in lengths of 1.83, 2.74 and 3.66 m, together with a wide range of fittings.

Jointing
A flexible push fit joint is used for cast iron and ductile iron pipes. A rubber gaskin, fitted inside the socket of pipes, comprises a heel of hardened rubber that aligns the pipes, and a bulb of softer rubber that makes the joint, as shown in Figure 12.63. The pipe ends must be clean and are lubricated and joined by leverage from a crowbar for small pipes, or a fork tool for larger pipes. The joint is flexible and will accommodate longitudinal and axial movements. The joint is rapidly made in any conditions of weather, the pipeline may be tested immediately and the trench can be backfilled to protect the pipeline.

obtainable in 1.83, 2.74 and 3.66 m lengths

effective length

bore sizes available
75, 100, 150 and 225 mm

socket

socket end of pipe

nominal bore of pipe

spigot

bead

spigot end of pipe, can
also be obtained with a
plain end without the bead
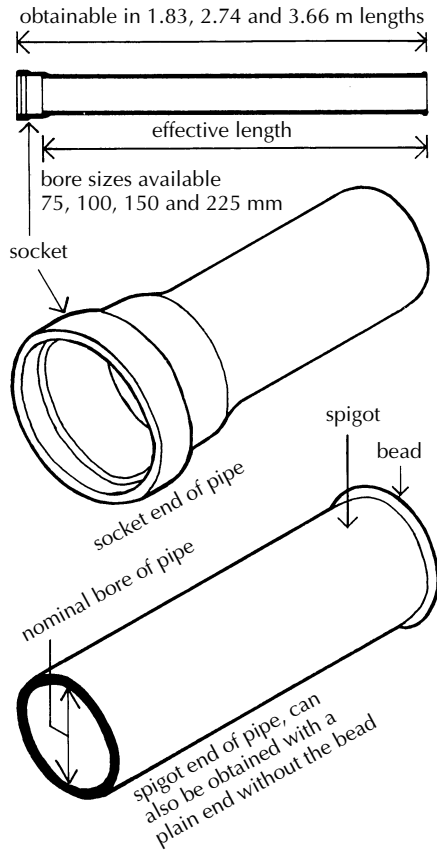
Figure 12.62   Cast iron drain pipes.

heel of hardened rubber

soft bulb of gasket

chamfered ends
to spigot

retaining bead
on inside of
socket
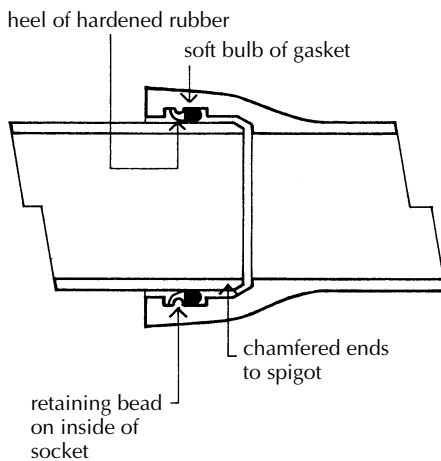
Figure 12.63   Flexible push fit joint for cast iron.
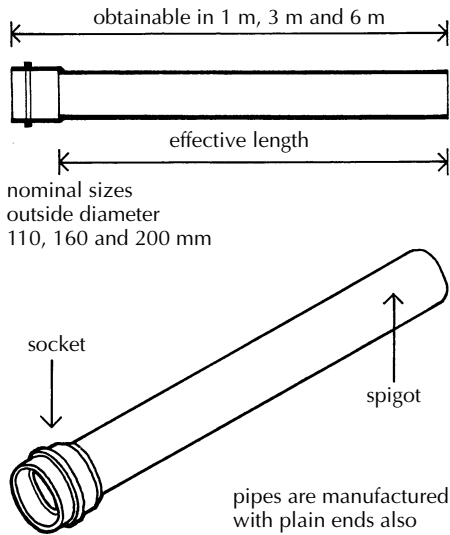
Figure 12.64   PVC drain pipes.

uPVC pipes
UPVC pipe is extensively used because of its ease of handling, cutting and jointing and the low cost. The pipe is light in weight and flexible as it can, to some extent, deform under load without fracture. Deformation should be limited to an increase in horizontal diameter of not more than 5% to avoid blockages in pipelines or breaks to joints. Pipe sizes are described by the outside diameter of the pipe as 110, 160 and 200 mm, and lengths are 1.0, 3.0 and 6.0 mm (Figure 12.64). Because of the comparatively long lengths in which this pipe material is made, with consequently few joints necessary, the material lends itself to assembly at ground level from where it can be lowered into narrow trenches.

Jointing
Socket and spigot push fit joints with rubber rings depend on a shaped socket end of pipe, as shown in Figure 12.65, or a shaped coupling designed to fit around rubber sealing rings that fit between the socket or coupling and spigot end to make a watertight seal. Because the rubber ring seal has to be a tight fit between the pipes, it requires careful manipulation to fit the spigot end into the socket end of the pipe or coupling while making certain the rubber seal takes up the correct position in the joint. Because of the considerable thermal expansion and contraction of this material it is necessary to provide for movement along the pipe lengths through the allowance between the spigot end of pipes and the shoulder on the socket end of the pipe or coupling, as illustrated in Figure 12.65. Several proprietary systems of push fit joints are available.
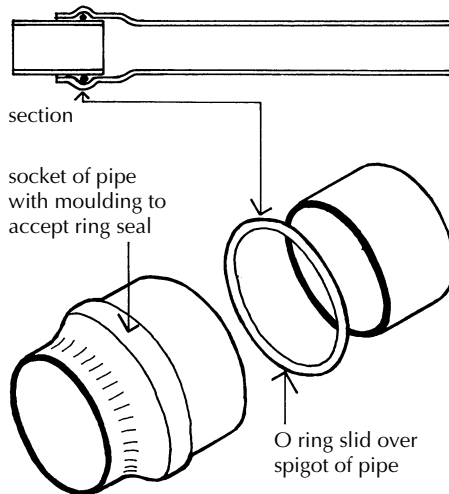
Figure 12.65   PVC socket and spigot push fit joint.

Sleeve joints of polypropylene with rubber sealing rings to plain-ended pipes depend on a separate plastic coupling sleeve that fits over the spigot ends of plain pipe lengths. Rubber seal rings in the ends of the sleeve compress on the spigot ends of the pipes being joined, as illustrated in Figure 12.66. To provide a tight fit between the coupling sleeve and the pipe ends it is necessary to apply some force to push the pipe ends into the sleeve, for which cramps or jacks are available. The ends of the pipes being joined fit to shoulders in the sleeve to provide the expansion allowance illustrated in Figure 12.66. Sleeve jointing is generally favoured over the socket and spigot joint.
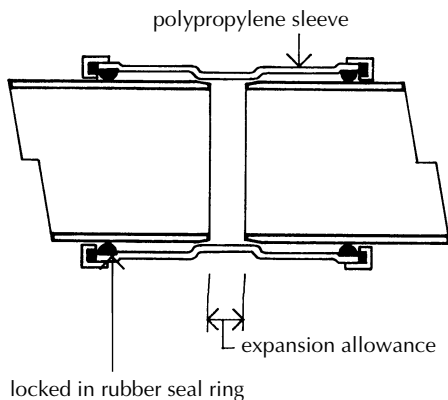
Figure 12.66   PVC sleeve joint.

pipe ends carefully cleaned before jointing

excess solvent wiped off

welded joint achieved by bringing
together spigot and socket of pipes which
have been brushed at the ends with
solvent – PVC solution and methyl chloride
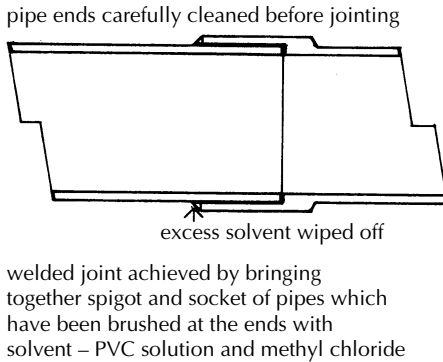
Figure 12.67   PVC solvent welded joint.

Solvent welded joints (Figure 12.67) are available for short lengths of drain pipe. This type of joint is not used for long lengths of drain, as the rigid joint makes no allowance for expansion. The joint is made by bringing together the spigot and socket ends of the pipe after they have been brushed with a PVC solution and methyl chloride. The solvent dissolves the PVC, which fuses together after some time. A disadvantage of this joint is that it takes some time to harden fully.

Drain pipes made of uPVC are commonly used with the proprietary drain systems, which comprise a package of plastic connections, clearing eyes, and access bowls for inspection, to combine economy and speed of assembly and laying. Because of the comparatively extensive range of fittings manufactured in clay, it is not uncommon for clay gullies, for example, to be used in conjunction with uPVC pipes.

Pitch-fibre pipes
Pitch-fibre pipes have been successfully used on the Continent and in America for many years. They were first manufactured and used in the UK from the middle of the twentieth century and were used for drains underground for both soil and surface water. The low cost, long length of pipe and ease of jointing, together with the flexibility of the material made the material popular. Pipes made of uPVC have largely taken over as the principal flexible drain pipe material.

Drain laying

Drains laid underground should be of sufficient diameter to carry the anticipated flow, and should be laid to a regular fall or gradient to carry the foul water and its content to the outfall.

Pipe gradient or fall

Research into the flow load of drains in use has shown that the size of the drain pipe and its gradient should be related to the anticipated flow rate in litres per second, so that the discharge entering a drain will determine the necessary size and gradient of the drain. For short drain runs the invert level at the top and bottom of the run can be pegged out at the correct level, and either sight lines or string lines used to plot the gradient of the pipe. Pipe lasers are more

A target is set level in the end of the pipe. The pipe is manoeuvred until the laser strikes the centre of the target

Laser provides a line at a set gradient for pipes to follow

The laser is positioned in the first pipe which is set at the correct level
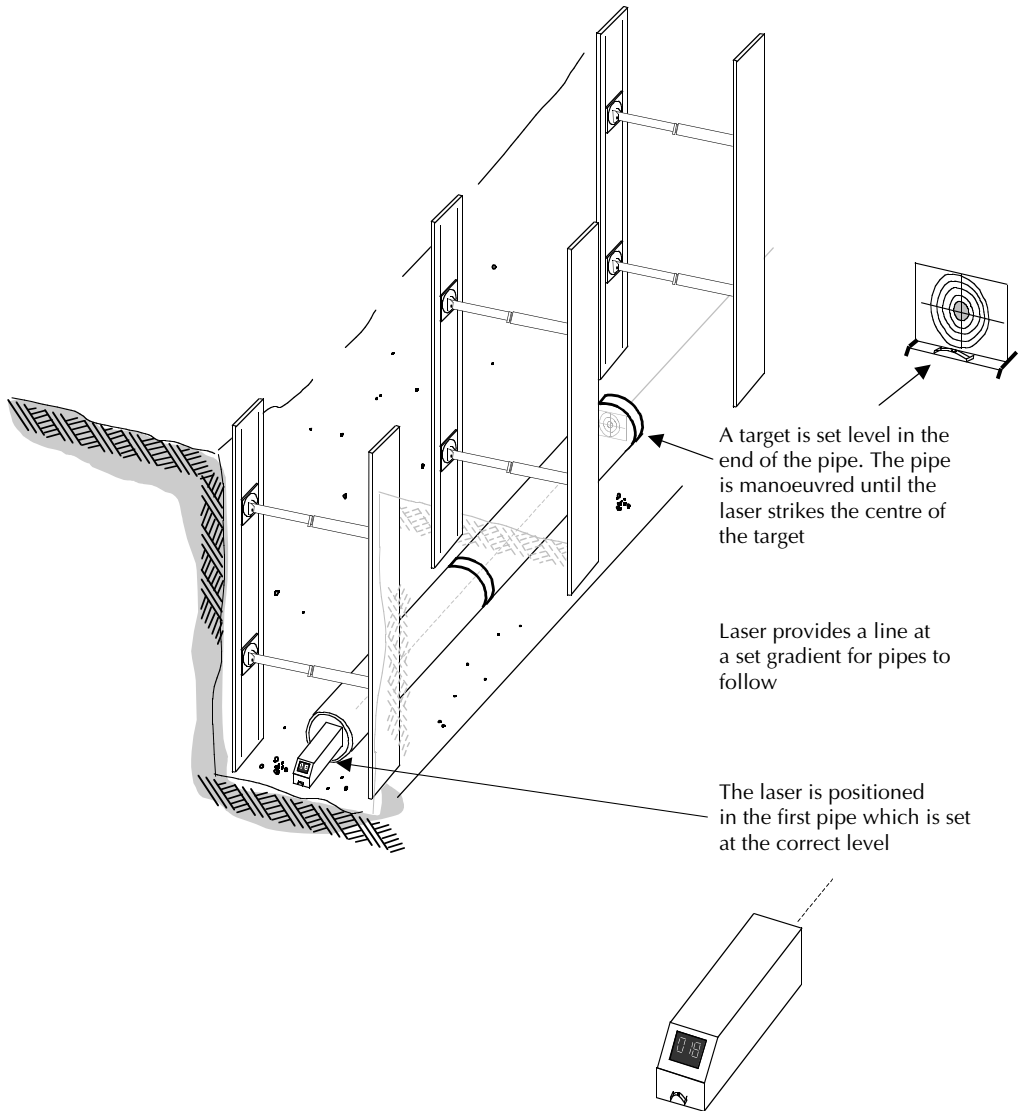
Figure 12.68   Laser set in pipe.
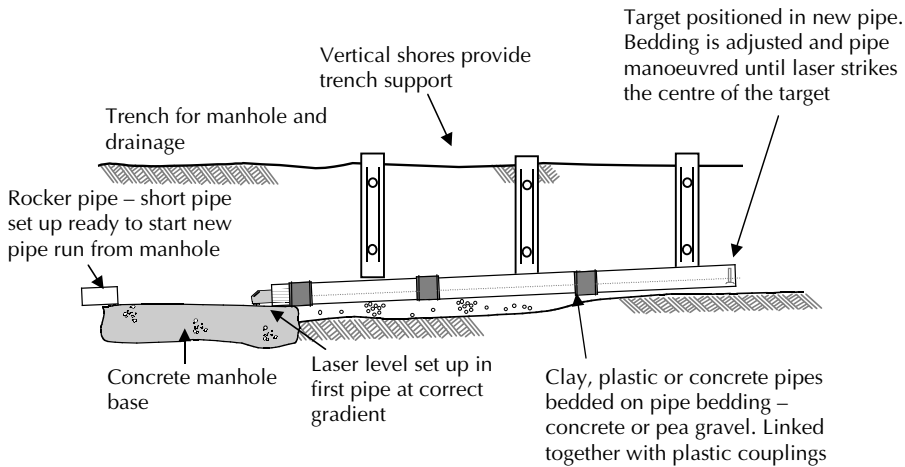
Figure 12.69   Section showing positioning of pipes using laser level.

commonly used today. The laser sits at one end of the pipe run and the target is positioned in the end of the pipe being levelled. When the laser strikes the centre of the target the pipe is at the correct level (Figures 12.68 and 12.69 and photograph 12.1).

Drains are designed to collect and discharge foul water and rainwater by the flow of water under gravity. Drains are, therefore, laid to a regular fall (slope) towards the sewer or outflow. The necessary least gradient or fall of a drain depends on the anticipated flow of water through it and the necessary size of drain to carry that flow. Table 12.3 gives recommended minimum gradients for foul drains.

Approved Document H1 recommends that a drain carrying only waste water should have a diameter of at least 75 mm, and a drain carrying soil water at least 100 mm. The term waste water is generally used to include the discharge from baths, basins and sinks, and soil water includes the discharge from WCs.

Table 12.3   Recommended minimum gradients for foul drains.

Peak flow (litres/sec)	Pipe size (mm)	Minimum gradient (1:. . .)	Maximum capacity (litres/sec)
<1	75	1:40	4.1
	100	1:40	9.2
>1	75	1:80	2.8
	100	1:80*	6.0
	150	1:150†	15.0

*Minimum of 1 WC.
†Minimum of 5 WCs.
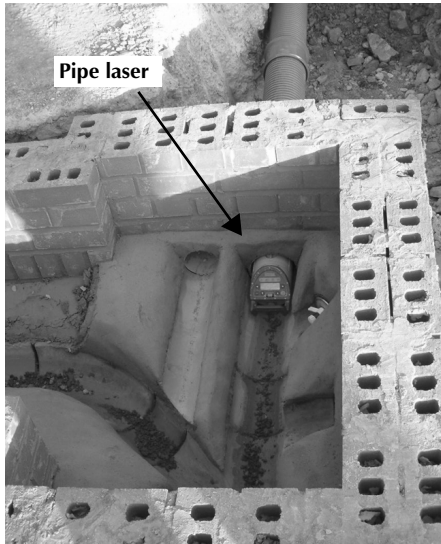
A   Laser set up in manhole. Once set at the correct gradient, pipes can be laid to the correct level

B   The laser can be used to obtain a level for the pipe bedding, the drainage is placed onto the bedding and positioned to correct fall

C   Once the pipe is correctly positioned pipe bedding covers the whole pipe
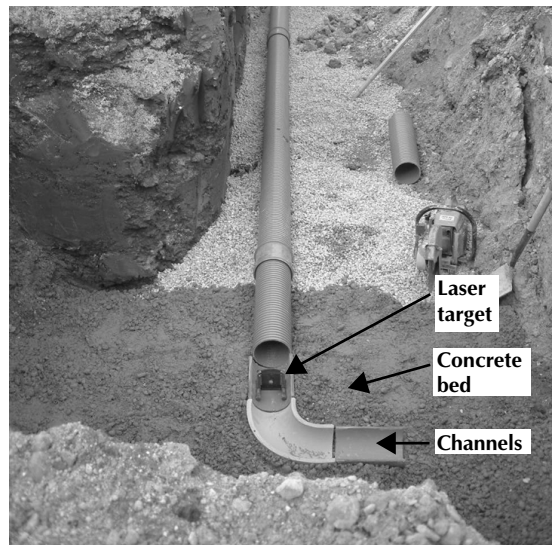
D   Channels laid on bed of concrete ready to form new manhole

Photograph 12.1   Laying drains.

Table 12.4   Discharge capacities of foul drains running 0.75 proportional depth.
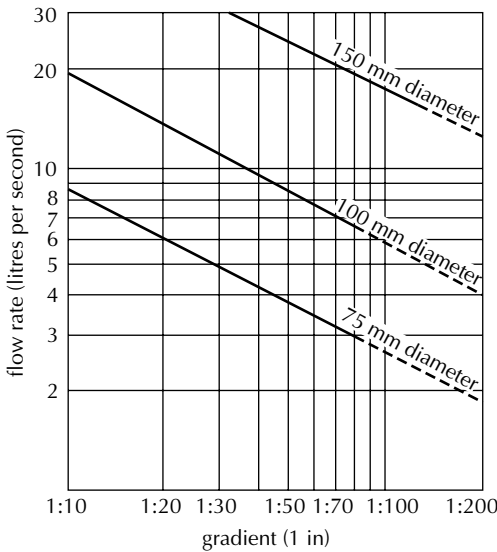
Table 12.4, from Approved Document H1, shows the relationship of flow rate to gradient for three pipe sizes with drains running three quarters of proportional depth. The rate of flow in drains with gradients as flat as 1:200 is given. Drains are not commonly run with gradients below 1:80 because the degree of accuracy necessary in setting out and laying drains required for shallow falls is beyond the skills of most building contractors.

Drains should be laid at a depth sufficient to provide cover for their protection and the excavation should be as narrow as practical for bedding and laying the drain lines. The greater the width of the trenches at the crown of the pipe, the greater the surcharge loads on the pipe. It is advantageous, therefore, to bed the drain in a narrow trench, which may be increased in width above the level of the crown of the drain for ease of working. With modern excavating machinery, flexible joint pipelines may be assembled above ground and then lowered into and bedded in comparatively narrow trenches, so saving labour and cost in excavation, improving health and safety and providing the best conditions for the least loads on the pipeline.

The depth of the cover to drain pipes depends on the depth at which connections are made to the drain, the gradient at which the pipes are laid and ground levels. Depth of cover is taken as the level of finished ground or paving above the top of a drain pipe. A minimum depth of cover is necessary to provide protection to the pipe against damage, and a maximum depth to avoid damage to the drain by the weight of the backfilling of the drain trenches. Minimum and maximum cover for rigid pipes are set out in Table 12.5. Flexible pipes should

Table 12.5   Limits of cover for standard strength rigid pipes in any width of trench.

Pipe bore	Bedding class	Fields and gardens		Light traffic roads		Heavy traffic roads	
		Min	Max	Min	Max	Min	Max
100	D or N	0.4	4.2	0.7	4.1	0.7	3.7
	F	0.3	5.8	0.5	5.8	0.5	5.5
	B	0.3	7.4	0.4	7.4	0.4	7.2
150	D or N	0.6	2.7	1.1	2.5	–	–
	F	0.6	3.9	0.7	3.8	0.7	3.3
	B	0.6	5.0	0.6	5.0	0.6	4.6

have a minimum of 0.6 m of cover under fields and gardens and 0.9 m under roads.

Bedding flexible pipes

Flexible pipes should be laid in a narrow trench, on granular material such as clean, natural aggregate. This granular material is spread in the base of a trench that has been excavated and roughly levelled to the gradient or fall of the drains. The granular material is spread and finished to a thickness of 100 mm, to the drain gradient. Lengths of drain pipe are then lowered into the trench and set in position by scooping out the granular bed from under the collars of pipe ends, to set the pipe line in place in the centre of the trench. Further granular material is then spread and lightly packed each side of the pipe line, to support it against deformation under load, as illustrated in Figure 12.70. A layer of granular material or selected fill, taken from the excavated material, is then spread over the pipe line to a depth of 100 mm. A further layer of selected fill, free from stones, lumps of clay or other material larger than 40 mm, is spread in the trench to a thickness of 200 mm. The trench is then backfilled with excavated material up to ground level, and consolidated. This drain laying operation requires care and some skill to bed the drain line correctly, and further care in backfilling to avoid disturbing the drain. Where the bed of the trench is narrow, it may be necessary to cut the sides of the trench above the level of the bed of the drain, in the form of a V, sloping out from the centre for ease of access.

Bedding rigid pipes

Where a drain trench is excavated in some cohesive soil such as clay for laying rigid pipelines of clayware, for example, it is possible to lay the pipes directly on the trench bottom which has been finished to the required pipe gradient by hand trimming by shovel. The pipe lengths are lowered into the trench and soil from the trench bottom is scooped out under each socket end of pipe so that the barrel of the pipes bears on the trench bottom and the collars keep the drain line in place. Figure 12.71 illustrates this type of bedding. For this operation to be successful, the trench needs to be sufficiently wide for a man to stand in
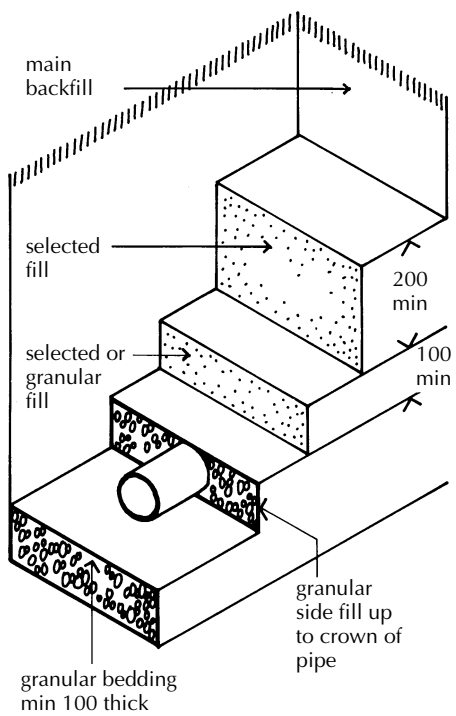
Figure 12.70   Bedding for flexible pipes.
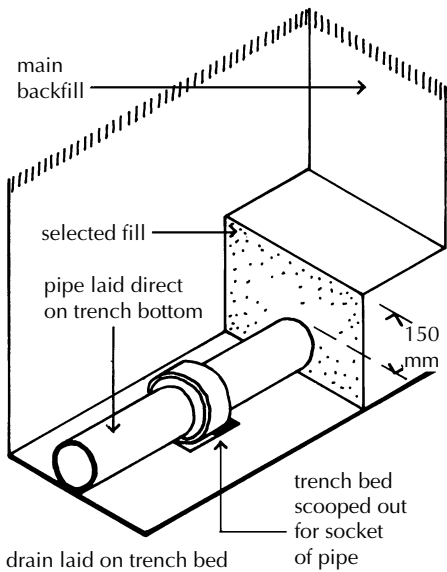
Figure 12.71   Bedding for rigid pipes – Class D.
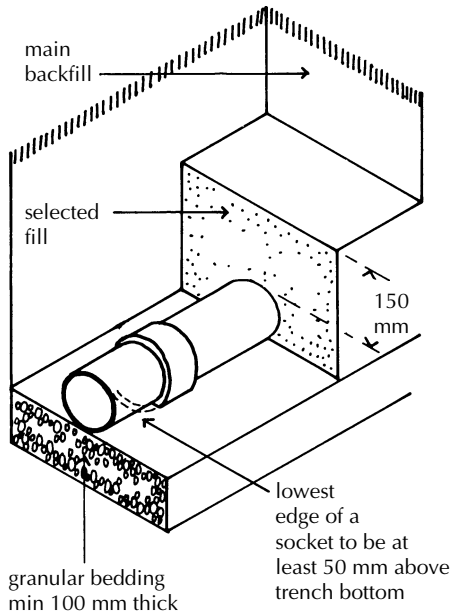
Figure 12.72   Bedding for rigid pipes: granular bedding – Class N.

the trench astraddle the pipeline to scoop soil out from below the pipe collars. Once the pipeline is in place, a cover of selected fill from the excavation, free from large stones or lumps of clay, is spread in the trench to a depth of 150 mm above the crown of the pipes, and the trench is backfilled to surface level. This bedding system is suited to the use of socket and spigot and clay pipes with one of the flexible joints that can be used in all weather conditions.

When the bed of drain trenches cannot be trimmed to the pipe gradient, a bed of granular material is spread in the bed of the trench and levelled to the pipe gradient to a thickness of 100 mm, as illustrated in Figure 12.72. The rigid pipes are lowered into the trench and a layer of selected fill is carefully spread around the pipes and then filled to a level 150 mm above the crown of the pipes. The trench is then back filled to surface level. This type of bedding is suited to plain clay pipes joined with flexible sleeves.

As an alternative, the granular bedding is spread 100 mm thick in the bed of the trench, the pipes are lowered into the trench and granular bedding is scooped out under the collar ends of pipes. The granular material is then spread around the pipes, up to half the outside diameter of pipe as shown in Figure 12.73. Selected fill is then spread in the trench to a depth of 150 mm above the crown of pipes, and the trench is backfilled to the surface. This system of bedding has the advantage that the granular bedding each side of the pipes maintains them in position as the trench is filled. It may well be that the most economical depth of flexible drain pipes below the surface will provide
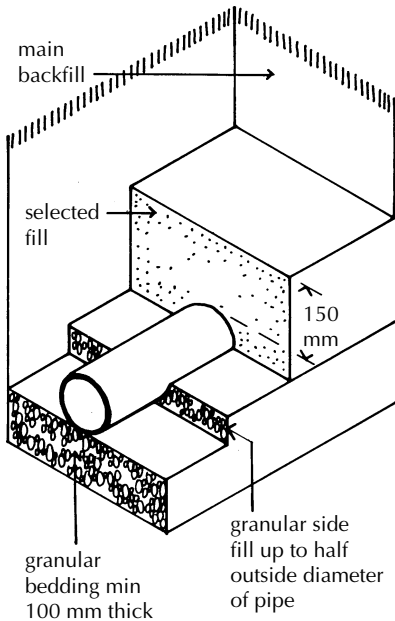
Figure 12.73   Bedding for rigid pipes: granular bedding – Class B.

less depth of cover than recommended. To avoid unnecessary excavation it is acceptable to lay flexible pipes with less cover when they are laid under fields or gardens. The pipes are laid on a bed of granular material 100 mm thick in the bed of the trench and then surrounded and covered with granular material up to a level of 75 mm above the crown of pipes, as illustrated in Figure 12.74. Concrete paving slabs are then laid over the granular material, bearing on offsets in the trench walls. The trench is then backfilled to surface level with selected fill from the excavation. The protection of concrete slabs and the granular material bed and surround of pipes will provide adequate protection against deformation of the pipes.

Rigid drain pipes that are laid at a depth that provides less than the recommended cover below surface, should be provided with protection from damage by an encasement of concrete, with flexible movement joints at each socket or sleeve joint of pipeline. The drain trench is filled with concrete, to a depth of 100 mm, in sections along the length of the trench equal to the pipe length. Between each section a 13 mm thick compressible board, holed for pipes, is set to the width of the trench. Before the concrete is hard it is scooped out for socket ends of pipe against one side of the board. A pipe is set in position up to the board and the next section of concrete is laid up to another flexible board in the trench. The concrete is scooped out for the next pipe, which is pushed into the flexible joint of the first pipe, and so on along the length of the trench, as illustrated in Figure 12.75. Once the drain line is laid it is tested and then concrete
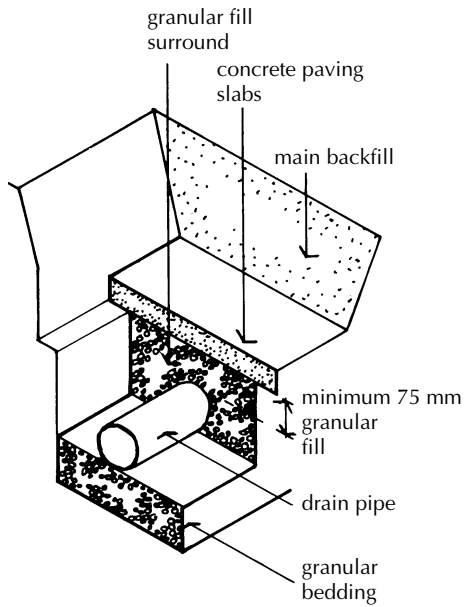
Figure 12.74   Protection for flexible pipes under fields and gardens.
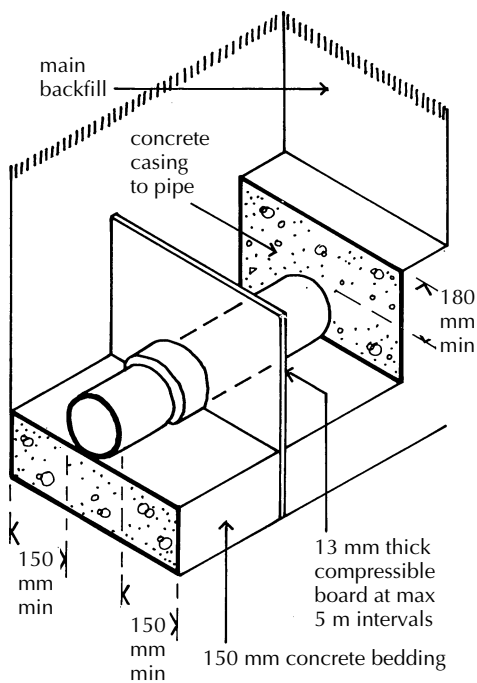
Figure 12.75   Concrete casing to rigid pipes.
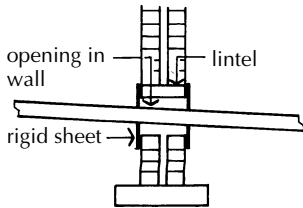
Figure 12.76   Drain pipe through opening in wall.

encasement is spread around the pipes, between the flexible boards, to provide a cover of 100 mm all round the drain. The trench is then backfilled to surface.

Drains under buildings and walls

When a drain is laid under a building and the crown of the pipes is at all points 300 mm or more below the underside of the ground floor slab, the drains should have flexible joints and be surrounded by granular material at least 100 mm thick all round the pipes. Where the crown of the drain is within 300 mm of the underside of the ground floor slab, it should be encased in concrete as an integral part of the slab.

There is a possibility that slight settlement of a wall might fracture the drain where it is laid to run through the wall under a building. There are two methods of avoiding the possibility of damage. The first method is to provide a minimum 50 mm clearance between the wall and the drain. The wall is built with a small lintel over the opening in the wall through which the pipe is to run, to provide at least 50 mm of clearance all round the drain. Where the drain is laid to run through the wall, two rigid sheets, holed for the pipe, are fitted to the pipe and secured in place by screws and plugs to the wall, as illustrated in Figure 12.76, to exclude vermin or fill. The disadvantage of this system is that it is difficult to provide a close fit of a rigid board to a pipe and to brickwork and to make a watertight joint between the external board and the wall.

The other method of providing protection to a drain run through a wall, is to provide for any slight settlement of the wall by means of rocker pipes. A short length of pipe is built into the wall, projecting no more than 150 mm each side
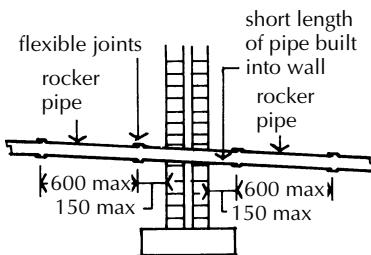
Figure 12.77   Drain pipe built into wall.
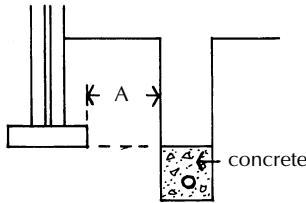
Figure 12.78   Drains less than 1 m from foundations.

of the wall. A length of pipe, at most 600 mm long, is connected to each end of the built-in pipe and connected to it with flexible joints. These rocker pipes are likewise connected to the drain line with flexible joints so that any slight movement of the pipe built into the wall is accommodated by the flexible joints of the rocker pipes. This system, illustrated in Figure 12.77, is best executed with plain clay pipes with flexible sleeve joints.

Drains close to buildings
On narrow building sites where there is only a narrow strip of land each side of a building, it may be necessary to run a drain parallel to a flank wall of the building.

To provide the necessary gradient or fall, the drain may be at or below the level of the wall foundation. To avoid the possibility of the loads on the wall foundation imposing undue pressure on the drain, it may be necessary to provide additional protection. Where the drain trench bottom is less than 1 m from the foundation, the distance indicated by the letter A in Figure 12.78, the drain should be laid on a bed of concrete and then covered with concrete up to the level of the underside of the wall foundation. A drain laid 1 m or more from the wall foundation, the distance indicated by the letter A in Figure 12.79, and appreciably below the foundation of the adjacent wall, should be bedded on concrete and then covered with concrete up to a level equal to the distance from the wall of A minus 150 mm. This additional protection, which is expensive,
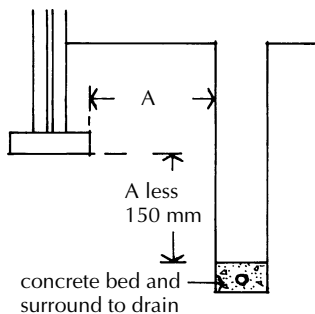
Figure 12.79   Drains 1 m or more from foundations.

Table 12.6   Minimum dimensions for access fittings and chambers.

Type	Depth to invert (m)	Internal sizes		Cover sizes	
		Length × width (mm × mm)	Circular (mm)	Length × width (mm × mm)	Circular (mm)
Rodding eye	–	As drain but min 100		–	
Access fitting		150 × 100	150	150 × 100	150
small	0.6 or less				
large		225 × 100	–	225 × 100	–
Inspection chamber	0.6 or less	–	190*	–	190*
	1.0 or less	450 × 450	450	450 × 450	450†
Manhole	1.5 or less	1200 × 750	1050	600 × 600	600
	over 1.5	1200 × 750	1200	600 × 600	600
	over 2.7	1200 × 840	1200	600 × 600	600
Shaft	over 2.7	900 × 840	900	600 × 600	600

*Drains up to 150 mm.
†For clayware or plastics may be reduced to 430 mm in order to provide support for cover and frame.

may not be wholly satisfactory as it provides rigid encasement that makes no allowance for possible differential settlement along the length of the drain run, which might fracture the encasement and pipe run.

Access points to drains

There should be adequate access points to drains to provide means of clearing blockages by rodding through drains. Rodding is the operation of pushing flexible, sectional rods that can be screwed together, down drain lines to clear blockages. The three types of access point in use are:

❑ Rodding eyes, which are capped extensions of drain pipes
❑ Access fittings, which are small chambers in, or as an extension of, drain pipes with no open channel
❑ Inspection chambers, which are large chambers with an open channel. Small inspection chambers have no working space at drain level; large inspection chambers (sometimes called 'manholes') do provide working space at drain level.

Access points should be provided on long drain runs and at or near the head of each drain run, at a bend or change of gradient, a change of pipe size and at junctions where each drain run to the junction cannot be cleared from an access point. The limits of the depth and minimum dimensions for access points are set out in Table 12.6 and the minimum spacing of access points in Table 12.7.

Inspection chamber
An inspection chamber is usually constructed as a brick-lined pit at the junction of drain branches and at changes of direction and gradient, to facilitate

Table 12.7 **Maximum spacing of access points in metres.**

From	To	Access fitting		Junction	Inspection chamber	Manhole
		Small	Large			
Start of external drain*		12	12	–	22	45
Rodding eye		22	22	22	45	45
Access fitting						
small 150 dia.		–	–	12	22	22
150 × 100		–	–	22	45	45
Inspection chamber		22	45	22	45	45
Manhole		22	45	45	45	90

*Connection from ground floor appliances or stack.

inspection, testing and clearing obstructions. An inspection chamber is formed on a 150 mm concrete bed, on which bricks walls are raised. In the bed of the chamber a half-round channel or invert takes the discharge from the branch drains, as illustrated in Figure 12.80. The walls of the chamber may be of dense engineering bricks. If less dense bricks are used the chamber is lined with cement rendering to facilitate cleaning, and sometimes it is rendered outside to prevent the infiltration of groundwater. The chamber is completed with a cast iron cover and frame.
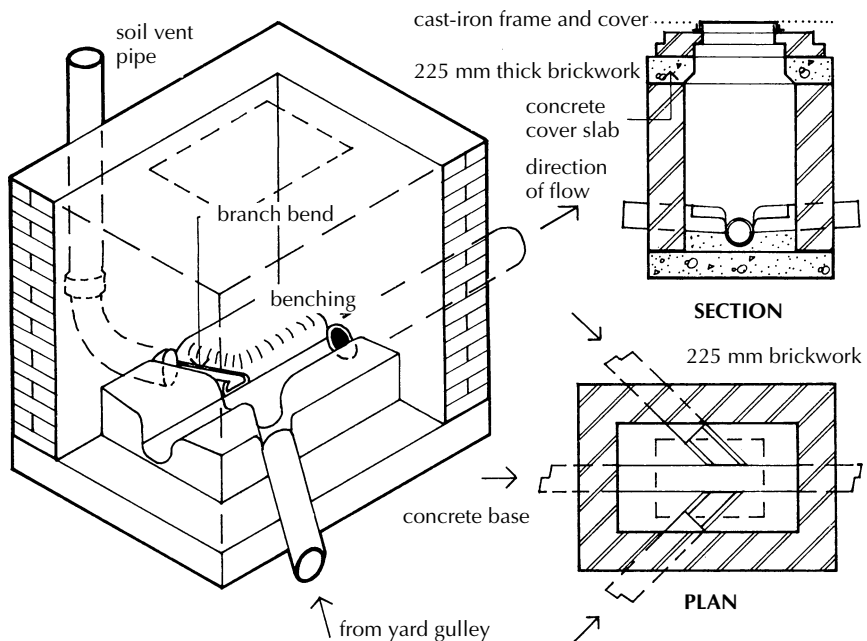
Figure 12.80   Cut-away sectional view of inspection chamber.

A   Pipe   **B   Half round channel**
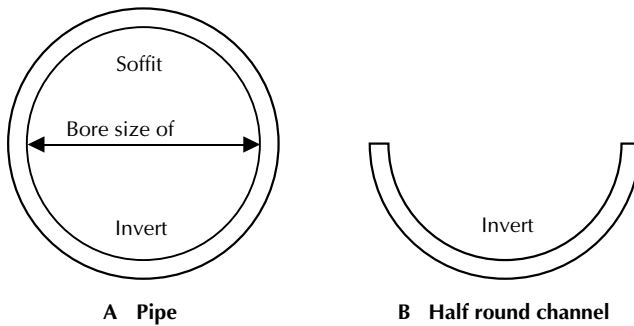
Figure 12.81   Section through drainage showing invert level.

The word invert is used to describe the lowest level of the inside of a channel in an inspection chamber, or the lowest point of the inside of a drain pipe, and measurements to the invert of a drain are used to determine the gradient of that drain (Figure 12.81). In the bed of the chamber the three-quarter section branch drains discharge over the channel in the direction of flow, and fine concrete and cement rendering termed benching is formed around the branches to encourage flow in the direction of the fall of the drain, as shown in Figure 12.80.

Backdrop inspection chamber

Where a branch drain is to be connected to a main drain or a sewer at a lower level, it is often economical to construct a backdrop inspection chamber to avoid deep excavation of a drain line. The backdrop chamber is constructed of brick on a concrete bed and the higher branch drain is connected to a vertical or drop drain that discharges to the channel in the backdrop chamber, as illustrated in Figure 12.82 (the near side and end walls are omitted for clarity). The drop drain is run in cast iron drains, supported by brackets screwed to plugs in the wall.

Access bowl drain system

Where uPVC drains are used for small buildings such as houses, a system of PVC access bowls or chambers may be used. The hemispherical access bowl (Figure 12.83) is supplied with one hole for the outlet drain, and up to five additional holes can be cut on site to suit inlet branches. Purpose-made inlet and outlet PVC connectors are provided for solvent welding to the bowl for outlet and inlet connections to drains. One access bowl is sited close to the building for the discharge from the soil pipe and ground floor foul water and waste water fittings. The access bowl is extended to ground level with PVC cylindrical extension sections, one of which is illustrated in Figure 12.83. The access bowl is set on a concrete bed and, after the drain runs have been connected, it is surrounded with a minimum of 100 mm of concrete for protection and stability. A cast iron frame and cover is set on top of the access bowl at ground level.
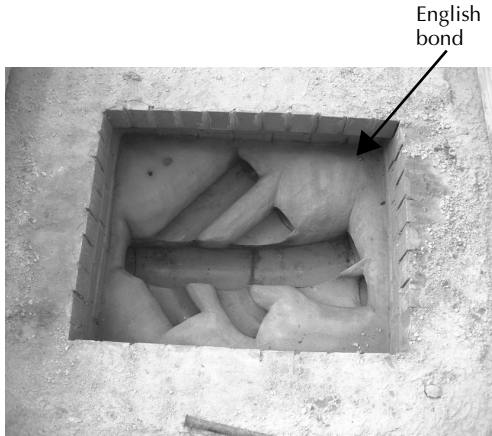
A   **Brick manhole – English bond**
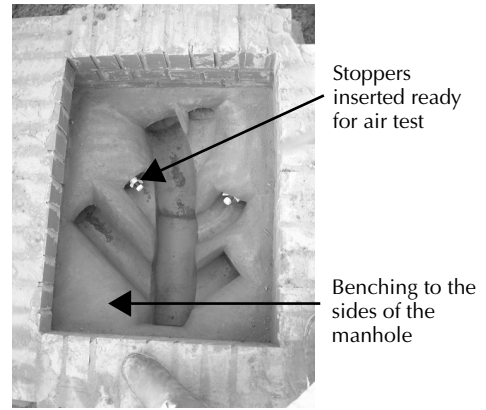
B   **Channels and benching in manhole**
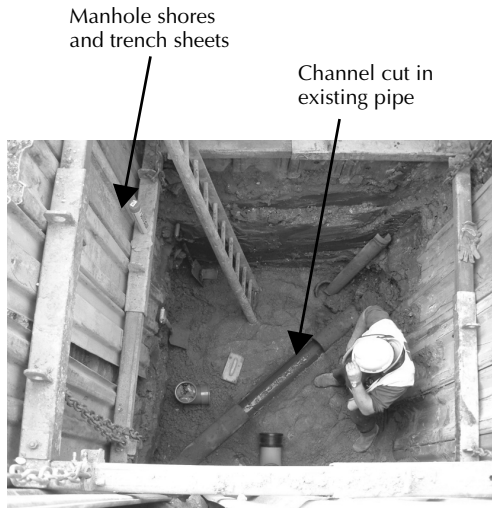
C   **Deep manhole: existing pipe run exposed ready to form a new manhole**
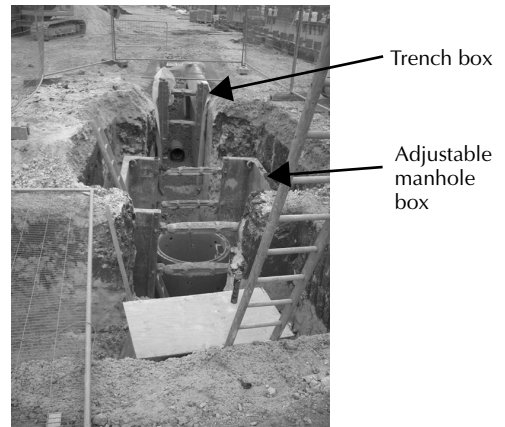
E   **Temporary ground support used to lay drains and form manholes**

Photograph 12.2   Laying manholes.

These access bowls may be used at changes of direction in drain lines and at the site boundary, before the connection to the sewer, for the purpose of rodding to clear blockages and inspection of flow. Access bowls can effect some cost saving compared with a brick inspection chamber.

Rodding point drain system

This sealed underground drain system combines the advantages of the long lengths of pipe and simplicity of jointing uPVC drain lines, with rodding points

galvanised malleable step-irons built
into courses of brickwork to
simplify access into deep drop
manholes, galvanised ladders
to be used in manholes
over 4.5 metres in depth

access bend

cast-iron pipework drop
inside manhole

open channel to
permit inspection
and clearance of
blockages

concrete base

direction of flow

concrete benching
finished with steel floated
cement mortar

Figure 12.82   Back drop manhole.

and one or more inspection chambers for access for inspection, testing and
clearing blockages. Figure 12.84 shows a typical layout. The rodding points are
used as a continuation of straight drain runs extended to ground level with
an access cap. It is possible to rod through each drain run to clear a blockage
and this arrangement dispenses with the need for inspection chambers at all
junctions and bends with appreciable saving in cost.

Soil stack pipe to connection drains
In the single stack system, a single pipe serves to carry both soil water and
waste water discharges directly down to the drains, so that the soil pipe or
stack may serve as a ventilation stack pipe to the drains. In this system the
water trap seals to each of the sanitary appliances serve as a barrier to drain
smells entering the building. At the base of the soil pipe is a large radius or easy
sweep bend to facilitate clearing blockages. Whether the soil pipe is run inside
or outside the building there should be a large radius bend at its connection
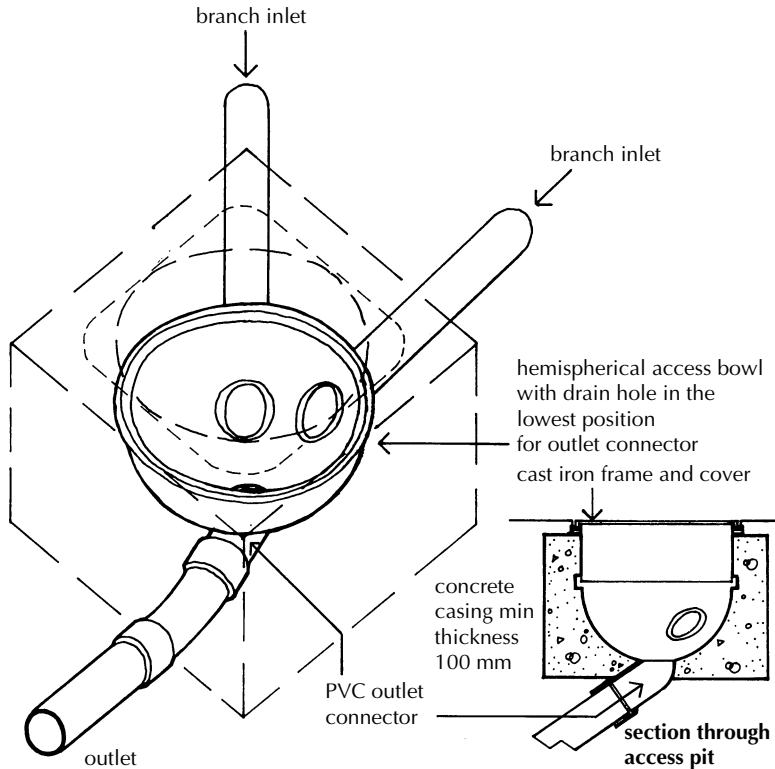
Figure 12.83   Mascar access bowl drain system.

to an inspection chamber. Where the drain connection to a soil or waste pipe passes through the wall of the building, there should be at least 50 mm of clearance all round the drain to allow for any settlement of the wall that might otherwise fracture the pipe if it were built into the wall. The opening in the wall around the pipe is supported by small lintels or brick arches and covered with rigid sheet both sides, as illustrated in Figure 12.85.

Gullies

Where there is a combined sewer that takes soil/waste water discharges and rainwater from roofs and paved areas, it is necessary to use a trapped gully at the foot of rainwater downpipes so that the water seal in the gully serves as a barrier to foul gases rising from the drains. The trapped gully illustrated in Figure 12.86 has a back inlet connection for the rainwater pipe and a grating that serves as access to clear blockages and to take water running off paved areas. These gullies are made with either back or side inlet connections for rainwater pipes.

Where there are separate drain and sewer systems for foul water and rain and surface water, the gullies that collect rainwater and surface water can be
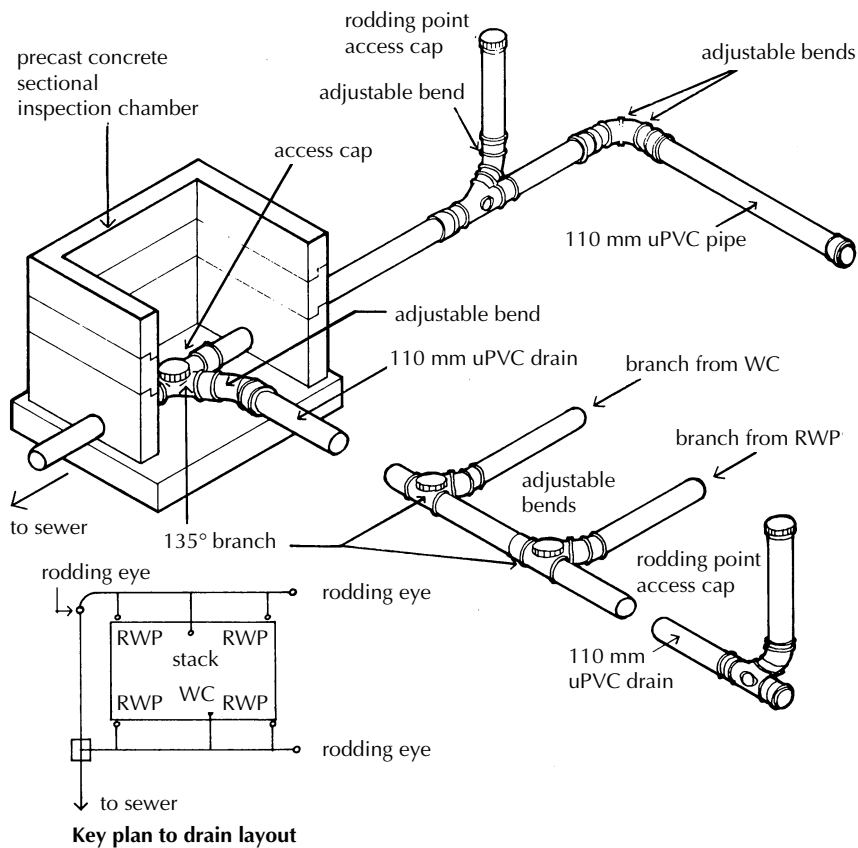
Figure 12.84   Rodding point drain system.
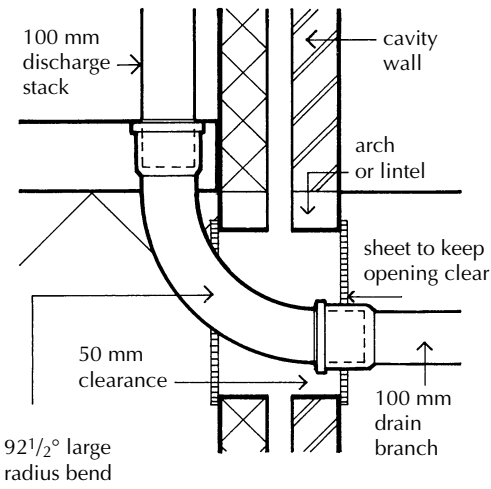
Figure 12.85   Soil stack connection to drain.
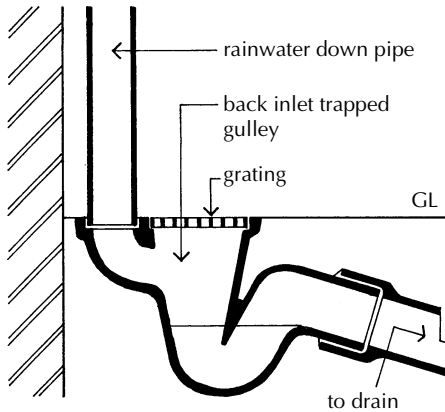
Figure 12.86   Trapped gully.

connected directly to the surface or storm water drain. The fitting (Figure 12.87) is described as a rainwater 'shoe' to differentiate it from a gully that has a water seal. The shoe has a grating that fits loosely into a tray to provide access.

As there is less likelihood of blockages in surface water drains than in soil water drains, it is not considered necessary to form inspection chambers at all junctions, bends and changes of gradient to the drain as is the case with foul water drains. Rodding eyes at salient points to facilitate clearing drains are generally considered adequate for the purpose. Because of the wide range of fittings available, it is common to use clayware gullies and rainwater shoes for most drain pipe materials. Gullies and shoes are usually bedded on a small concrete base to provide a solid base for connection to stack pipes and drains.
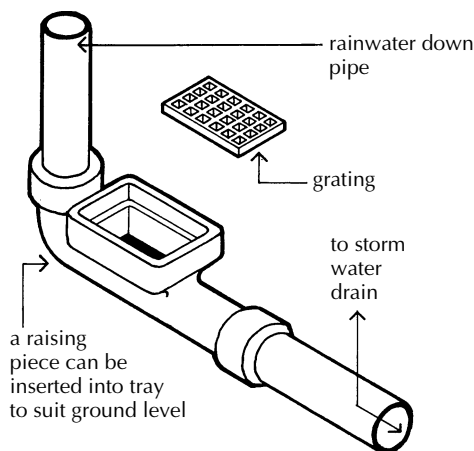
Figure 12.87   Rainwater shoe.
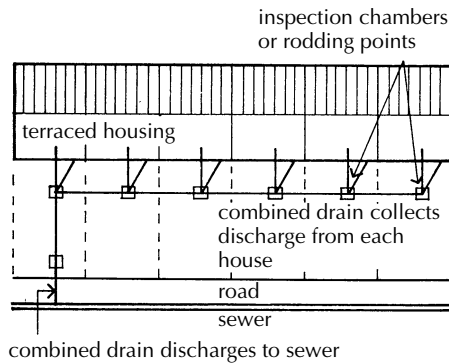
Figure 12.88   Common drain.

Private sewers, common drain

There is no exact distinction between the words drain and sewer, but the most generally accepted definition is that pipelines under privately owned land, laid and maintained by the owner, are called drains, and pipelines laid and maintained by the local authority under roads are called sewers. A private sewer, also termed a combined drain, is a system of drains laid for the use of two or more buildings, paid for and maintained by the owners of the buildings and making one connection to the public sewers. A common drain or sewer to a terrace of houses such as that illustrated in Figure 12.88 requires one drain connection to the public sewer. Where properties do not directly front on to public roads and sewers, as is common in houses such as those shown in Figure 12.89, it is convenient to lay a private sewer by use of a combined drain, making one connection to the public sewer rather than separate connections
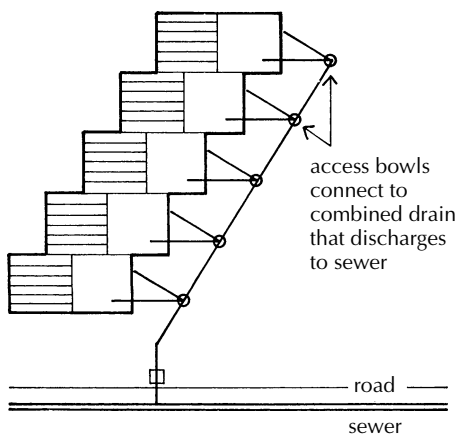
Figure 12.89   Combined drains (private sewers).

from each house. Having laid a private sewer or combined drain it is necessary to apportion the cost of maintenance work to it.

Connections to sewers
Connections to public sewers are generally made by the local authority or made by the building owner's contractor under the supervision of the local authority. In both cases the connection is paid for by the building owner. In new developments a branch connection is constructed in a new sewer, which is then connected to an existing sewer.

Drain testing

All newly laid drain lines should be tested for water tightness after jointing and laying and again after backfilling and consolidation of trenches. Existing drains may also need to be tested. The methods available are as follows.

Water test
The drain is tested by water pressure, applied by stopping the low end of the drain and filling it with water to a minimum head of water, as illustrated in Figure 12.90. The head of water should be 1.5 m above the crown of the high end of the pipeline under test. Where long drain lines are to be tested, and the head of water would exceed 6 m due to the length and gradient of the drain, it is necessary to test in two or more sections along the line. The loss of water over a period of 30 minutes should be measured by adding water from a measuring vessel at regular intervals of 10 minutes, and noting the quantity required to maintain the original water level. The average quantity added should not exceed 1 litre per hour per linear metre, per metre of nominal internal diameter. The water test is a test of water tightness under pressure, a condition that a freely flowing drain will never suffer, and is thus a test of water tightness far more rigorous than the drain line is designed for.
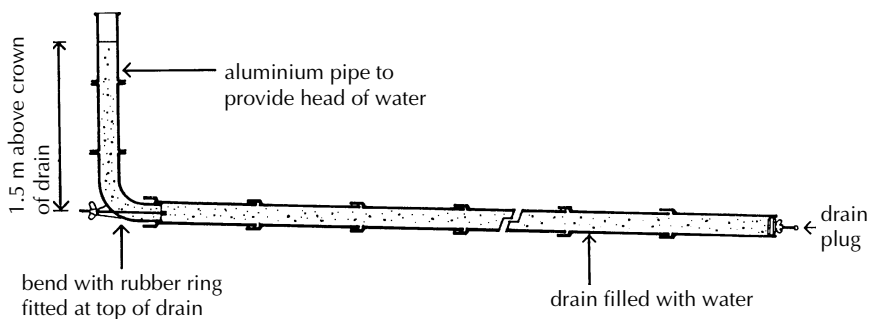
Figure 12.90   Water test.
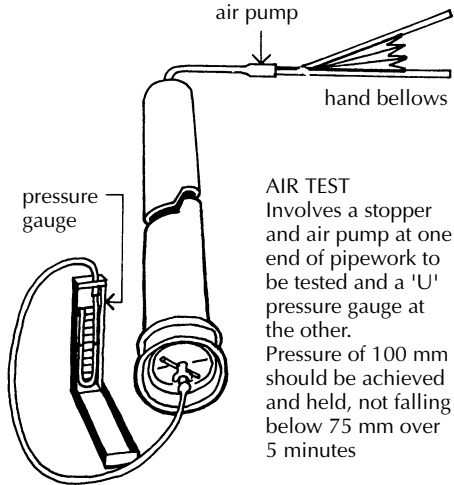
Figure 12.91   Air test.

Air test

The air test is generally accepted as less rigorous test than the water test. The drain line is stoppered at both ends and air pressure is provided by a pump, the pressure being measured by a graduated U-tube or manometer, as shown in Figure 12.91. Expanding drain stoppers suited to take the tube from the pump at one end of the drain line and the tube to the pressure gauge or manometer at the other, are fitted to the ends of the drain line to be tested. Air pressure is applied to the drain through a hand or foot operated pump until a pressure of 100 mmHg is recorded on the graduated U-section pressure gauge and the valve to the gauge is shut. An initial period of 5 minutes is allowed for temperature stabilisation and the pressure is then adjusted to 100 mmHg. The pressure recorded by the U-gauge or manometer should then not fall below 75 mm over a further 5 minutes for a satisfactory test. Where trapped gullies and ground floor appliances are connected to the drain line being tested, a pressure of 50 mmHg is adopted as the measure.

Smoke test

The smoke test has been used for old drains where the water or the air test is too rigorous. The drain is stoppered at suitable intervals and smoke is introduced under pressure from a smoke capsule or smoke machine. The purpose of the tests is to discover leaks by the escape of smoke, either when the line has been uncovered or is underground. An escape of smoke will find its way to the surface through a considerable depth of soil and all but the most dense concrete cover. Figure 12.92 illustrates a smoke test machine. The reason for using a smoke test, particularly on old drains, is to give some indication of
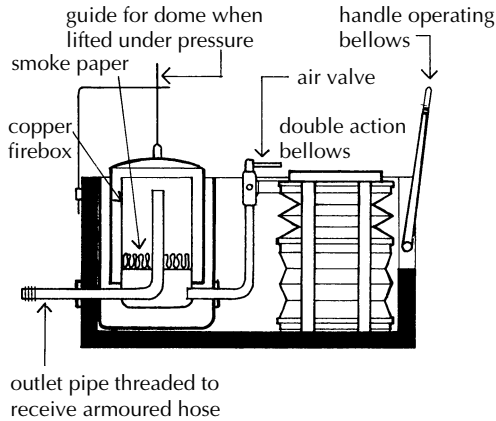
Figure 12.92   Eclipse smoke testing machine.

the whereabouts of likely leaks before any excavation to expose drains has been undertaken. This may be of use on long runs of drain and where drains run under buildings. The appearance and smell of smoke may give a useful indication as to where excavation to expose drains should take place. Water, air and smoke tests act on the whole of the internal surface of drains. These tests may indicate leaks due to cracks in the crown of the drain. As drains never run full bore, a crack in the crown of a drain may not cause any significant leakage and may not warrant repair.

CCT surveys
Modern technology provides a means of making visual inspection of the inside of drain runs by the use of a small camera that is inserted into and run down the line of a drain to provide a moving picture record on a monitor of the view of the inside of the drain. This is usually recorded on a video cassette or computer disc and can be used to obtain an extent of work required before excavation begins.

Sewage collection and treatment

In areas where connection to a main sewer is not possible it is necessary to use a cesspool, septic tank or sewage treatment plant. It is necessary to make sure that the installation conforms to current pollution prevention requirements and is appropriate for the intended purpose. Advice is available from local authority environmental control officers.

Cesspool
A cesspool is an underground chamber or container used to collect and store all foul and waste water from buildings. They are emptied by pumping the
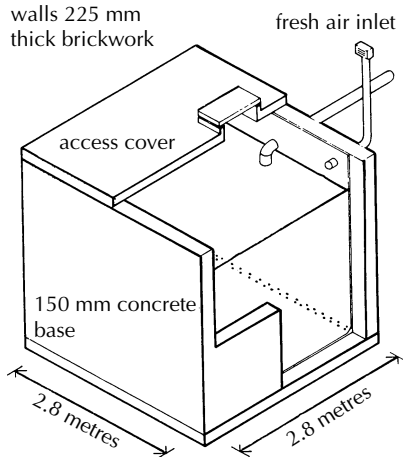
Figure 12.93   Cesspool.

contents to a tanker. Cesspools are used only in outlying areas where there is no ready access to a sewer and where ground is waterlogged or the slope of the site does not allow the use of a more compact and convenient septic tank. The traditional cesspool was a brick lined pit, such as that illustrated in Figure 12.93, with engineering brick walls 220 mm thick, lined inside with cement and sand rendering on a concrete base. A reinforced concrete cover over the cesspool would be formed at, or just above, ground level with some form of access cover for emptying and a fresh air inlet. A range of prefabricated cesspools is available today. These are made from glass reinforced fibre plastic (GRP) in the form of sealed containers with capacities of 7500 to 54 000 litres. Larger capacities of up to 240 000 litres can be made. The ribbed cylindrical cesspool, with access point, inlet and fresh air inlet (FAI), is delivered ready to lower into an excavated pit with the cylinder lying on its long axis. The cesspool is laid on a bed of concrete and surrounded with a lean mix of concrete, with the cover to the access point at or just above ground level.

Septic tank
A septic tank is designed to take the outflow of soil and waste water, retain some solid organic matter for partial purification, and discharge the liquid sewage through a system of land drains to the surrounding ground to complete the process of purification. The usual capacity of septic tanks is from 2800 to 6000 litres for from 4 to 22 people respectively. A range of moulded, high grade polyethylene, bulb-shaped tanks is manufactured, with access turret, inflow and outflow connections and a fresh air inlet (Figure 12.94).

The tank is bedded on concrete and surrounded with lean mix concrete with the access cover at or just above ground level. The septic tank is divided into
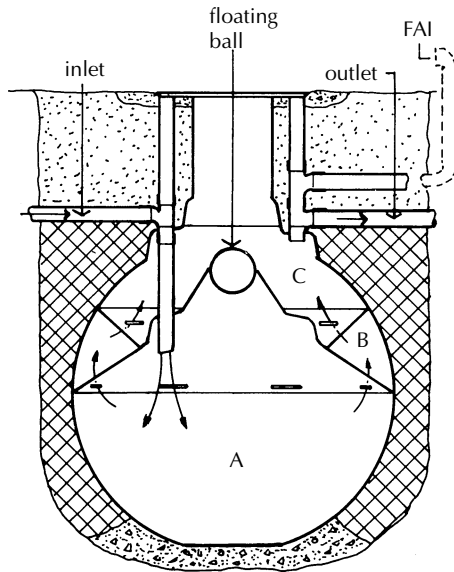
Figure 12.94   Prefabricated septic tank.

three chambers. The outflow of the foul and waste water drains is discharged to the lower chamber (A in Figure 12.94) in which the larger solid particles of sewage settle to the bottom of the chamber. As more sewage flows down the inlet, liquid rises through the slots in the bell shaped division over the lower chamber and enters the middle chamber (B). In this chamber fine particles of solid matter settle on top of the bell shaped division and settle through the slots into the lower chamber. As the tank fills, liquid now comparatively free of solid sewage matter rises through the slots in the inverted bell shaped division to the third and upper chamber (C). As this upper chamber fills, the now partially purified liquid rises through the outflow to a system of perforated land drains.

The land or leaching drains, laid in trenches surrounded by granular material, spread the liquid sewage over an area sufficiently large to encourage further purification of the liquid sewage by aeration and the action of microorganisms in sewage. The accumulated sludge of solid sewage that settles in the base of the tank should be removed at intervals of not more than 12 months to a tanker. A hose from the tanker first empties the upper chamber, by suction. As the liquid level falls, the ball that seals the division between the upper and middle chambers falls away. This provides access to remove the sludge from the lower chamber.

Sewage treatment plant

The preferred and more expensive system for sewage outflow, where no sewer is readily available, is the installation of a sewage treatment plant that will

produce a purified liquid outflow that can be discharged to nearby ditches and streams without causing pollution of water supplies. A form of sedimentation tank, similar to a septic tank, causes solid sewage to settle. The resultant liquid outflow is further purified by exposure to air to accelerate the natural effect of micro-organisms, native to sewage, combining with oxygen to purify the sewage. The three systems used to speed the exposure of the liquid sewage to air are:

(1) By spreading over a filter bed
(2) By spreading over rotating discs
(3) By pumping in air to combine with the liquid (aeration)

The traditional sewage treatment plant, such as that illustrated in Figure 12.95, comprises a settlement tank which acts in the same way as a septic tank to
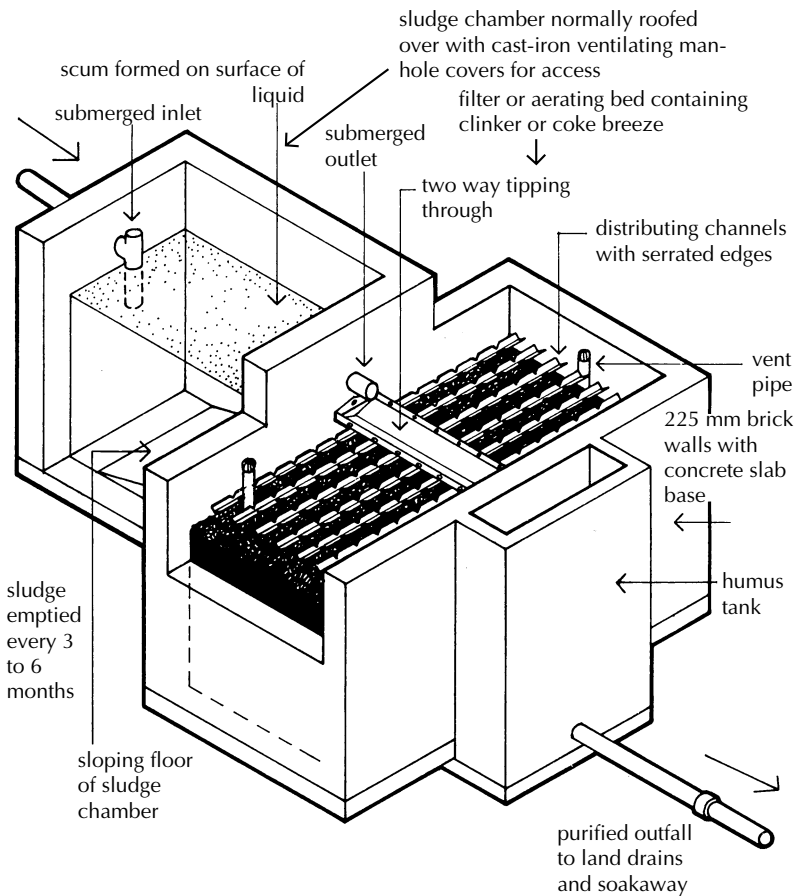
Figure 12.95   Sewage treatment plant.

allow solid matter to sink to the bed of the chamber either naturally or assisted by baffles. A range of prefabricated treatments is available from specialist suppliers.

Natural systems
In more rural areas it may be possible to discharge the foul water to specially designed and constructed reed beds (ponds), which naturally filter the waste. Advice should, in the first instance, be sought from the appropriate local authority, and then experts in this specialist area.

12.4 Roof drainage

Functional requirements
The primary function of roof drainage is to get rainwater from the roof to a suitable discharge as quickly and economically as possible, thus helping to prevent water penetration to the inside of the building.

Design considerations
Rainwater running off both pitched and flat roofs is usually collected by gutters and outlets and discharged by rainwater downpipes to drains, sewers or soakaways. More recently, emphasis has been placed on recycling the rainwater, via storage tanks, to flush WCs using grey water.

Rainwater gutters and downpipes are a prime source of dampness in walls if poorly designed and maintained. Gutters that are blocked, cracked or have sunk may cause persistent saturation of isolated areas of wall, leading to damp staining and possible dry rot in timbers. Gutters are not readily visible to building owners and are generally difficult to access for regular clearing of leaves and other accumulated debris.

The size of gutters and down pipes is determined by the estimated volume of rainwater that will fall directly on a roof during periods of intense rainfall. It is practice to use gutters and rainwater downpipes large enough to collect, contain and discharge water that falls during short periods of intense rainfall that occur during storms.

Drainage to pitched roofs

To determine the amount of water that may fall on a pitched roof it is necessary to make allowance for the pitch of the roof and for wind driven rain that may fall obliquely on a slope facing the wind. A larger allowance for wind driven rain is made for rain falling on steeply sloping roofs than on roofs with a shallow slope. The effective area of roof to be drained is derived from the plan (horizontal) area of a roof multiplied by a factor allowing for the pitch or slope of the roof, as set out in Table 12.8. Having determined the effective area of a roof slope to be drained it is necessary to select a size of gutter capable of

Table 12.8   Calculation of area drained.

Type of surface	Design area (m^2)
flat roof	plan area of relevant portion
pitched roof at 30°	plan area of portion × 1.15
pitched roof at 45°	plan area of portion × 1.40
pitched roof at 60°	plan area of portion × 2.00
pitched roof over 70° or any wall	elevational area × 0.5

collecting and discharging the volume of water assumed to fall during storms. For the purpose of choosing a gutter size, it is assumed that the roof drains to a half round gutter up to 8 m long with a sharp edged outlet at one end only and laid level.

Most gutters are laid with a slight fall to encourage flow, and the majority of plastic eaves gutters have round cornered outlets to encourage discharge, whereas square cornered gutter outlets, such as those in cast iron, impede flow, as illustrated in Figure 12.96. In the calculation of rainwater downpipe sizes some reduction of pipe size may be effected by the use of round edged gutter outlets.

To make the best use of the gutter it is usual to fix it to fall towards each side of an outlet to economise on gutter size and number of rainwater pipes. In the examples shown in Figure 12.97 it would be possible to use two rainwater pipes, one at each end of the roof, with the gutter falling each way from the centre of the roof. Each half of the length of gutter would have to collect more rainwater than any one length of fall shown in Figure 12.97, and a large gutter would be required. The length of a gutter between outlets to rainwater downpipes will depend on the position and number of rainwater pipes related to economy and convenience in drain runs (and position of windows and doors, etc.), which in turn will determine the area of roof that drains to a particular gutter length or lengths.
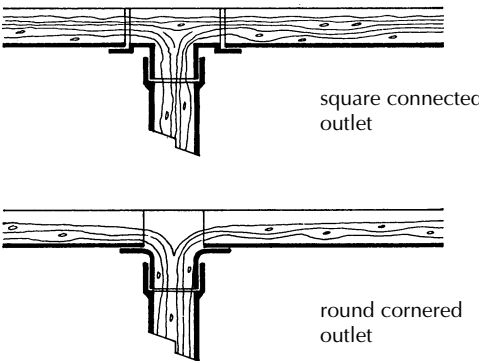
Figure 12.96   Rainwater outlets.
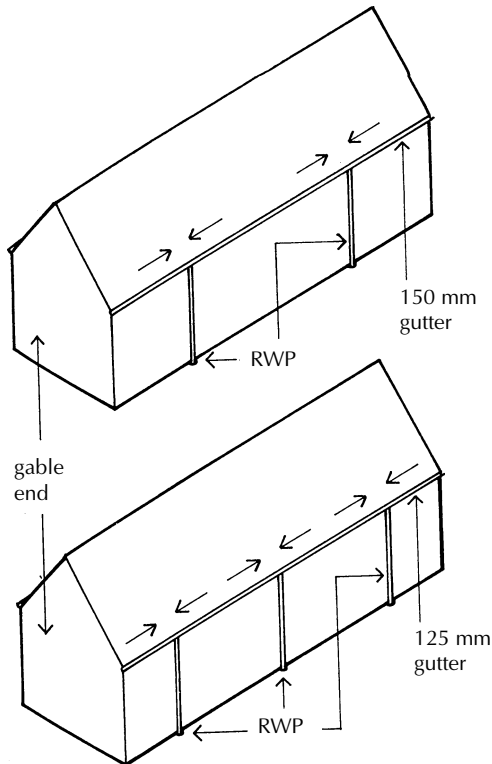
Figure 12.97   Gutters and downpipes.

Table 12.9 gives an indication of the required diameter of half round gutter sizes related to the maximum effective area of roof that drains to that gutter, where the gutter is fixed level and the outlets are square edged. The figure given for flow capacity in gutters is given in litres per second, which is derived from rain falling on the relevant effective area of roof in millimetres per second where

Table 12.9   Gutter sizes and outlet sizes.

Max roof area (m^2)	Gutter size (mm dia)	Outlet size (mm dia)	Flow capacity (litres/sec)
6.0	–	–	–
18.0	75	50	0.38
37.0	100	63	0.78
53.0	115	63	1.11
65.0	125	75	1.37
103.0	150	89	2.16

Refers to half round eaves gutters laid level with outlet at one end sharp edged. Round edged outlets allow smaller downpipe sizes.
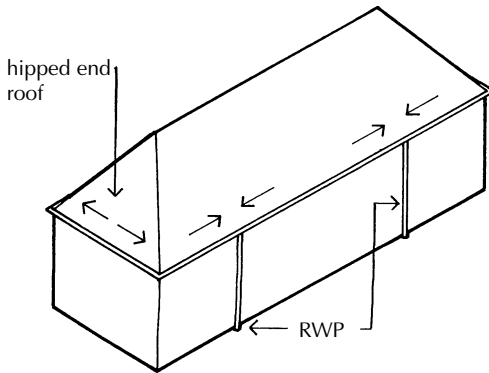
Figure 12.98   Hipped end roof.

a cubic metre of water equals 1000 litres. This figure may be used to check gutter sizes chosen against manufacturers' recommended flow capacities of gutters. The gutter outlet sizes will determine the size of rainwater downpipe to be used. For the majority of small buildings, such as single houses and small bungalows, a gutter with a diameter of 75 mm or 100 mm is adequate for the small flows between outlets.

Eaves gutters to hipped roofs are fixed to collect rainwater from all four slopes with angle fittings at corners, as shown in Figure 12.98, to allow water to run from the hipped end slope to the outlets to main slopes. In Figure 12.98 two downpipes are shown to each main roof slope, with the gutter to the hipped ends draining each way to the gutters to the main roof slopes. A square angle in a gutter, within 4 m of an outlet, somewhat impedes flow, and allowance is made for this in the calculation of flow in gutters. Flooding and overflow of eaves gutters to hip ended roofs most commonly occur at angles where obstruction to the flow is greatest, blockages are most likely to occur and the angle gutter fittings may sink out of alignment. Eaves gutters are usually fixed to a shallow fall of 1:360 towards outlets. This shallow fall avoids too large a gap between the edge of the roof covering and the low point of the gutter, yet is sufficient to encourage flow in the gutter and make allowance for any slight bow or settlement of the gutter.

Gutter sections
The section of gutter most commonly used for pitched roofs is the half round gutter. Other sections are available, such as the segmental and ogee or OG gutter illustrated in Figure 12.99. The segmental may be used to collect rainwater from small shallow pitched roofs. Gutter lengths and their associated fittings have spigot and socket ends so that the plain (spigot) end of the gutter fits to the shaped (socket) end of the gutter to provide a level bed of gutter. The necessary fittings to gutters are running outlets, stop end outlets, angles both

segmental gutter

half round gutter

ogee or OG gutter

Figure 12.99   Rainwater gutter cross-sections.

internal and external, and stop ends. These fittings have socket ends to fit the spigot ends of the section of gutter.

Figure 12.100 shows typical plastic gutter fittings for half round gutters. The angle fitting shown is an external angle fitting. Internal angle fittings are

outlet

stop end outlet

stop end

90° angle
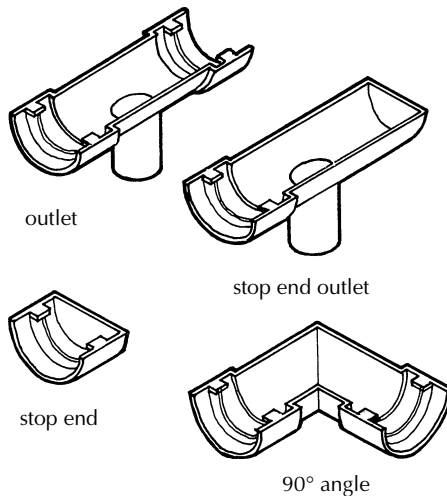
Figure 12.100   Rainwater gutter fittings.
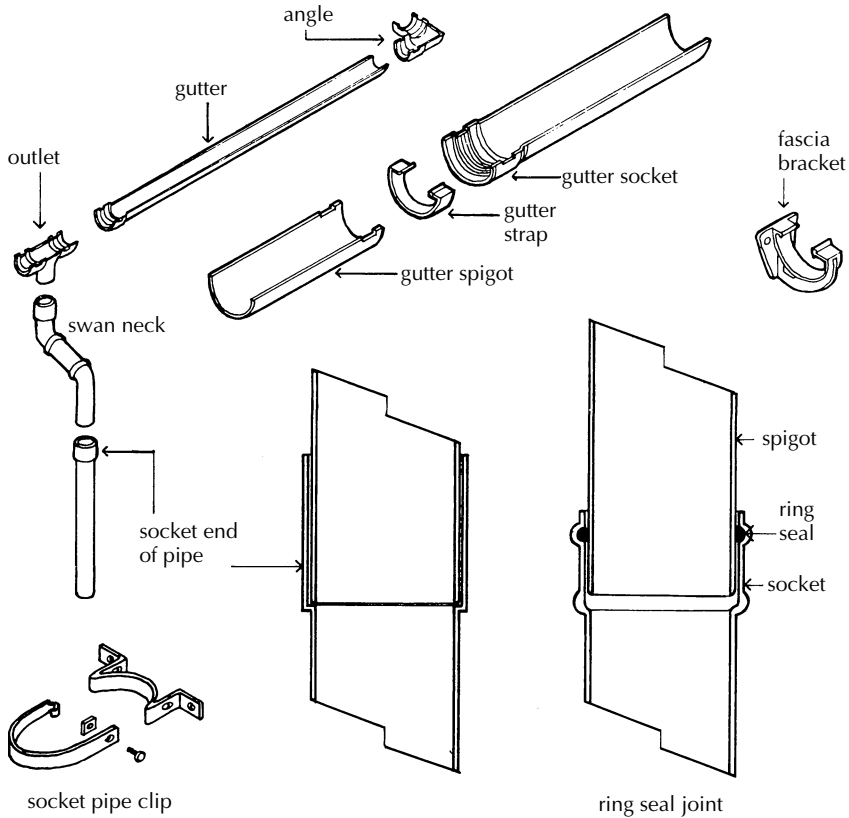
Figure 12.101   uPVC rainwater gutters and downpipes.

used where a wing or part of a building butts to another part at 90°. uPVC gutter sections with spigot and socket ends and angles, outlet and stop end fittings, are commonly used to drain the majority of pitched roofs today. uPVC is a lightweight material that needs no protective coating, is moderately rigid and has a smooth surface that encourages flow. This material is used for its comparatively low cost, ease of handling and freedom from maintenance.

Figure 12.101 shows uPVC gutters. Flexible seals are bedded in the socket ends of both gutters and fittings. These seals are watertight and at the same time are sufficiently flexible to accommodate the appreciable thermal expansion and contraction that is characteristic of this material. Without the flexibility of the seals, long lengths of gutter might otherwise deform. The joint between spigot and socket ends is secured with a gutter strap clipped around the gutter.

Gutter lengths are supported by plastic fascia brackets that are screwed to fascia boards. The gutter is pressed into the fascia brackets so that the lips of the bracket clip over the edges of the gutter to keep it in place. The spacing of the brackets is determined by the section of gutter used. Rainwater downpipes

are moulded with plain spigot and shaped socket ends. Socket ends are shaped to make the close fitting joint to spigot ends, or moulded to take a flexible ring seal as illustrated in Figure 12.101. The former makes a reasonably close fit and the latter a more positive watertight fit. The shaped fitting or fittings from the gutter outlet to the downpipe are formed to make allowance for overhanging eaves so that water discharge is directed from the gutter towards the downpipe fixed to walls.

The swan neck fittings are either moulded in one piece to accommodate particular dimensions of eaves overhang, or consist of three fittings to allow for various eaves overhangs. The swan neck shown in Figure 12.101 comprises three units: two bends and a short straight length used to allow for a particular eaves overhang. Rainwater downpipes are secured to walls with plastic pipe clips screwed to walls and the two piece pipe clip facilitates fixing plugs and screws to the wall.

Cast iron rainwater gutters and downpipes

Cast iron was the traditional material for gutters and downpipes for pitched roofs. Standard gutters are of half-round or ogee section with socket and spigot ends with angle, outlet and stop end fittings. The advantage of cast iron as a gutter material is that it is much less likely to sag than uPVC. Its disadvantage is that it is heavy and is liable to rust and should be coated to inhibit decay. The gutter joints are bedded in red lead putty or mastic and bolted together. Gutter lengths are supported by fascia or rafter brackets for half-round gutters and by screws or brackets for ogee gutters. Figure 12.102 shows a cast iron gutter and downpipe.
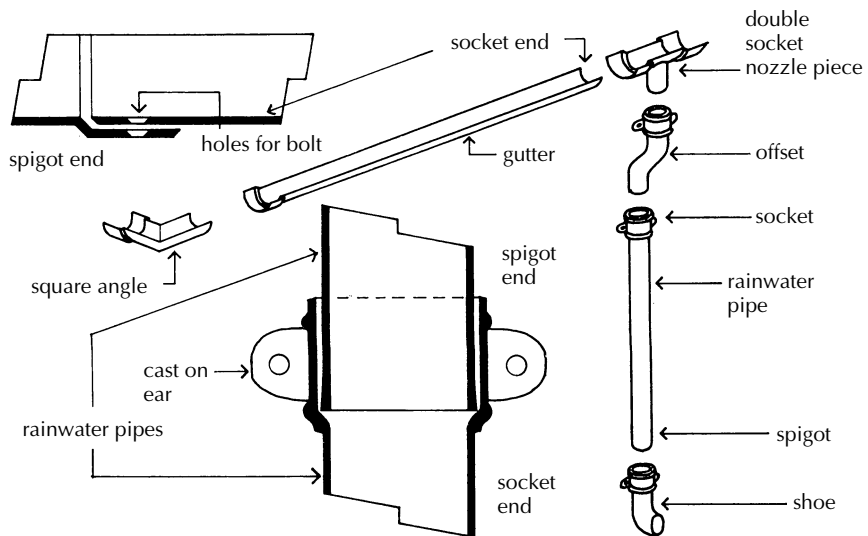
Figure 12.102   Cast iron rainwater gutter and pipe.
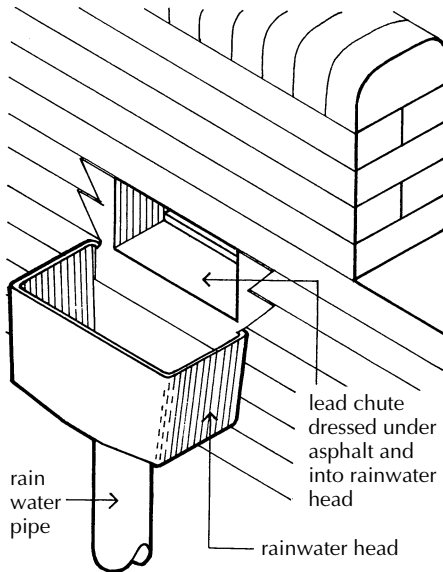
Figure 12.103   Parapet rainwater outlet.

Drainage to flat roofs

Flat roofs are often surrounded by parapet walls raised above the level of the roof finish. The run off of rainwater is encouraged by a fall or slope of the roof to outlets formed in the parapet wall. These outlets are lined with lead sheet shaped to fit in the bed and side of the outlet and are dressed down over a rainwater head, illustrated in Figure 12.103. The lead chute is dressed under the flat roof covering. Because the run off of rainwater is comparatively slow, fairly close spacing of outlets is necessary for drainage.

Rainwater heads are usually of galvanised or galvanised plastic coated pressed steel with an outlet to the rainwater downpipe. The traditional cast iron rainwater head is little used because of its cost and the need for regular coating or painting to avoid unsightly rusting. Where a flat roof is carried over boundary walls it discharges rainwater to an eaves or boundary wall gutter.

Large expanses of flat roof should drain to outlets in the roof as well as boundary outlets to avoid extensive lengths of fall or slope to flat roofs. Outlets are formed in the roof in some position where the necessary rainwater downpipe may be fixed to part of the supporting structure, such as a column. These outlets are shaped so that the roof covering may finish to the outlet with a watertight joint. Figure 12.104 is an illustration of an outlet to a flat roof covered with asphalt, with a lift-up grating to facilitate clearing of blockages.
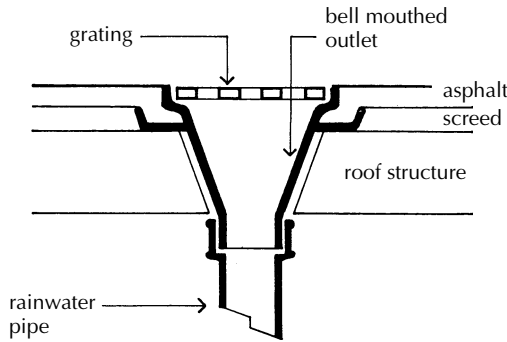
Figure 12.104   Rainwater outlet.

12.5 Surface water drainage

External surfaces that are paved with concrete, natural or artificial paving slabs, bricks or granite sets, should be laid with slight slopes or falls to gullies or channels. They should also be laid to fall away from the external walls of buildings to prevent the possibility of water collecting at the base of a wall. The fall helps to discharge rainwater reasonably quickly for the convenience of people and to prevent ponding of water that would accelerate deterioration of paving materials by saturation and the effect of frost on water lying in fissures in the material. A minimum fall of 1:60 is generally recommended for paved areas on flat ground. To economise in drain runs, paved areas should drain in two or more directions to yard gullies, with drainage channels between gullies in large paved areas to effect further economies. The drainage of the paved area in Figure 12.105 is arranged by each way falls to channels that, in turn, drain to gullies.
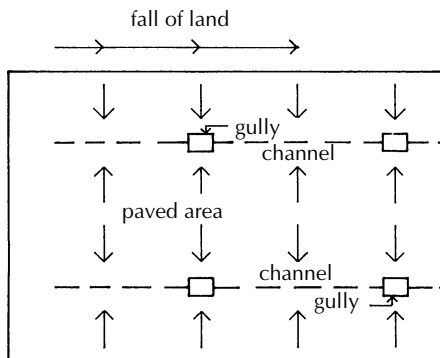
Figure 12.105   Paved area drainage.
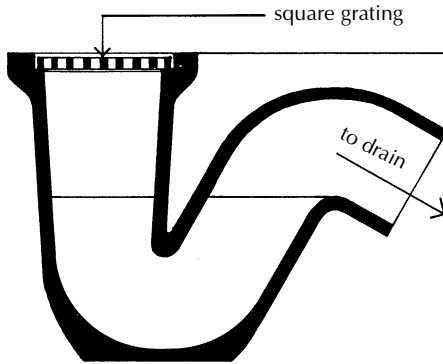
Figure 12.106   Clay yard gully.

Channels

Channels between gullies may be level and depend on natural run off or may be laid to a slight fall by a gentle sinking towards a gully. A small square area of paving may be laid to fall to one central gully, with channels formed from each corner to the gully by the intersection of slopes. Forming this slope at intersections of falls, termed a current, may involve oblique cutting of paving slabs or bricks to provide a level surface. Yard or surface water gullies are set on a concrete bed to finish just below the paved surface. The gullies generally have a 100 mm square inlet and are either trapped with a waterseal when they discharge to combined drains or are untrapped for discharge to a separate storm water drain. Figure 12.106 shows a trapped clay yard gully with loose cast iron grating for access to clear blockages. The graph in Figure 12.107 indicates the area of paving that can be drained relative to the estimated flow and size of the drain and to the gradient or fall.

Drainage systems

Where there are separate drainage systems, roof and surface water drainage will connect to a separate system of underground drains discharging to the sewer. For the rain and surface water drains, it will generally be satisfactory to have a system of either clay or uPVC drains with rodding eye access fittings as necessary and an inspection chamber near the boundary. The description of pipe laying, bedding and gradient for foul water drains will apply equally to roof and surface water drains for which untrapped gullies are used.

Soakaways

A soakaway is a pit into which roof and surface water is drained and from which the water seeps into the surrounding ground (Figure 12.108). Soakaways are used where a combined sewer may not be capable of taking more water,
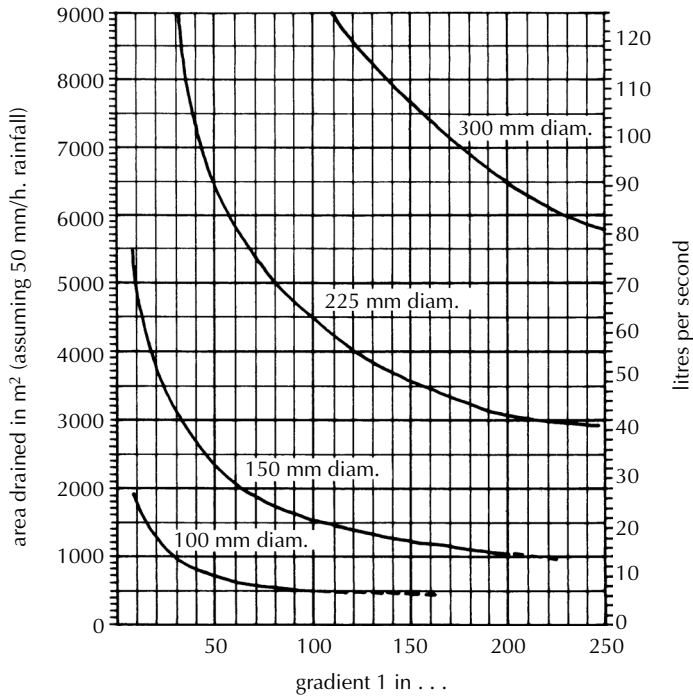
Figure 12.107   Graph for determining diameter and gradient of surface water drains.

where a separate rain and surface water sewer is distant. It can also be used as an alternative means of discharge. Outside the more densely built-up urban areas there is often an adequate area of land surrounding the building to use soakaways. If the soil is waterlogged and the water table or natural level of subsoil water is near the surface it is pointless to construct a soakaway. In this situation the surface water will have to be discharged by pipe to the nearest sewer, stream, river or pond. Soakaways should be positioned at least 3 m away from buildings so that the soakaway water does not affect the buildings' foundations, and they should also be on slopes down from buildings rather than towards buildings, to avoid overflowing and flooding.

12.6 Refuse storage and recycling

Waste is a result of our inefficient use of resources. As consumers we generate a lot of waste, much of which can be recycled. Until relatively recently it was common practice to put all of the household waste into the refuse bin for collection by the local authority refuse collection service. With increased awareness of ecological issues, combined with increased costs of refuse disposal, we are getting better at sorting our rubbish into defined categories of waste for recycling or disposal as appropriate. Environmental pressures and legislation
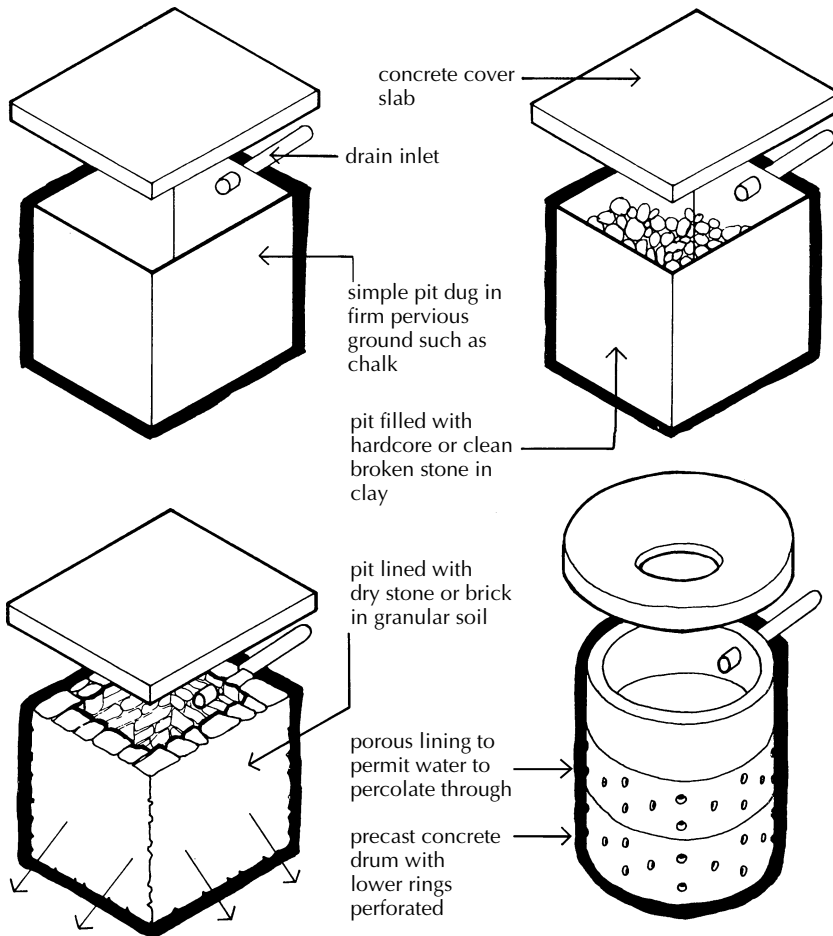
Figure 12.108   Soakaways.

from Europe and the UK have resulted in increasingly stringent targets being placed on local authorities and businesses to recycle more and hence reduce waste to landfill sites. New markets are emerging based on recycling glass, paper, plastics, wood and organic materials. Indeed, there has been a steady rise in the number of building product manufacturers who produce products from recycled material. Local authorities differ in the way in which they collect refuse; however, they provide the means to separate out paper and glass from the remainder of household waste.

Refuse bins

A good quality plastic refuse (garbage) bin, such as that illustrated in Figure 12.109, has taper sides without flutes or corrugations, a reinforcing rim, lifting handles, and a loose lid. Usual capacities are $0.071\,m^2$ and $0.092\,m^2$
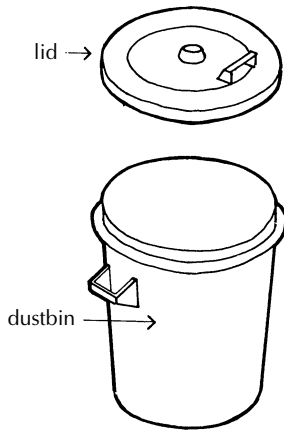
Figure 12.109   Plastic dustbin.

square section plastic bins on wheels ('wheelybins') and are supplied by some local authorities to reduce the labour of collection. These are supplemented with small, colour coded, plastic boxes to place glass and paper for separate collection and subsequent recycling.

Refuse containers

Refuse containers are large metal containers in which refuse, both domestic and trade, is stored. The limit to the size of these containers is the capacity of a collection vehicle to lift and carry or tow away the container, often described as a Paladin container. These galvanised steel containers are wheeled for man-handling to the collection vehicle, which is designed to lift, upturn and empty the contents into the rear of the collection vehicle. To this end there are various lifting attachments to the container such as the studs shown in Figure 12.110 or
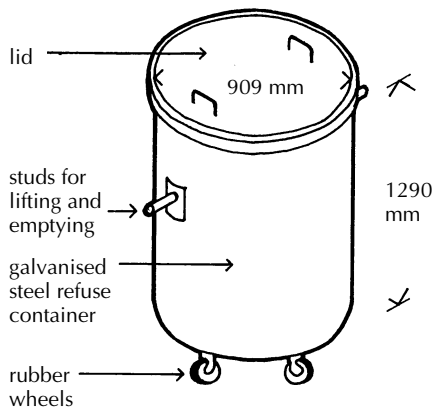
Figure 12.110   Galvanised mild steel refuse storage container.
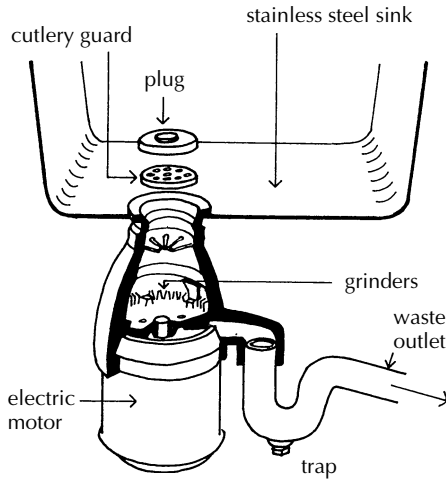
Figure 12.111   Waste disposal unit.

angle iron rims to suit the various makes of collection vehicle. These standard 0.95 m² refuse containers are extensively used at the foot of chutes for communal and trade refuse. A wide variety of large, purpose-constructed, galvanised steel containers are available. Paladins should be positioned so as to be easily accessible for filling and emptying, but so as to be out of view of the public.

Sink waste disposal units

Kitchen waste is fed through the sink waste to a disposal unit in which a grinder, powered by a small electric motor, reduces the refuse to small particles that are washed down with the wastewater from the sink. These units are designed to dispose of such kitchen refuse as food remains, which rot and cause disagreeable odours in bins. They are not suited to the disposal of larger bulky lightweight refuse. Figure 12.111 is an illustration of one of these units.

Appendix A: Web Sites

The number of online sources is very extensive. However, we have tried to provide a few well known addresses to help readers. Many of the sites have links to associated information and sites.

Building Regulations and Building Control

www.safety.odpm.gov.uk/bregs (for Approved Documents and Robust Details)

www.buildingcontrol.org (covers England and Wales and Northern Ireland)

www.scotland.gov.uk (covers Scotland)

Product information and trade associations

A large number of trade associations exist to promote the interests of their members, primarily through the publication and dissemination of technical literature. Well known examples are the Brick Development Association (BDA) and the Timber Research and Development Association (TRADA), but many more exist and are a good source of information. Information on building products and associated documentation is available online via a number of suppliers, the most well known are:

Barbour Index	www.buildingproductexpert.co.uk
RIBA Product Selector	www.productselector.co.uk
Specify It	www.specify-it.com

Site investigation – useful web sites

Regulators, guidance and policy-makers

Department for the Environment, Food and Rural Affairs	www.defra.gov.uk
Department for Transport, Local Government and the Regions	www.dtlr.gov.uk
Department for Trade and Industry	www.dti.gov.uk
Scottish Office – Scottish Executive	www.scotland.gov.uk
Welsh Assembly	www.wales.gov.uk
Department of Environment (Northern Ireland)	www.doeni.gov.uk
English Heritage	www.english-heritage.org.uk
Environment and Heritage Service in Northern Ireland	www.ehsni.gov.uk

Environment Agency	www.environment-agency. gov.uk
HM Customs and Excise	www.hmce.gov.uk
Scottish Environment Protection Agency	www.sepa.gov.uk
Scotland and Northern Ireland Forum for Environmental Research (SNIFFER)	www.sepa.gov.uk
Welsh Historic Monuments Executive Agency (CADW)	www.cadw.wales.gov.uk.
Health and Safety Executive	www.hse.gov.uk
Highways Agency	www.highways.gov.uk
Historic Scotland	www.historic-scotland.gov.uk
Parliamentary Office of Science and Technology	www.dti.gov.uk/ost

Research organisations and professional bodies

Association of Geotechnical and Geoenvironmental Specialists	www.ags.org.uk
Association of Researchers in Construction Management	www.arcom.ac.uk
British Drilling Association	www.britishdrillingassociation. co.uk
British Geological Survey	www.bgs.ac.uk
British Institute of Architectural Technologists	www.biat.org.uk
British Standards Institution	www.bsi-global.com
British Urban Regeneration Association	www.bura.org.uk
Building Research Establishment	www.bre.co.uk
Chartered Institute of Building	www.ciob.org.uk
Chemical Industries Association	www.cia.org.uk
Construction Industry Research and Information Association (CIRIA)	www.ciria.org.uk
Confederation of British Industry	www.cbi.org.uk
English Heritage	www.english-heritage.org.uk
English Nature	www.english-nature.org.uk
ExSiteResearch Ltd – Brownfield regeneration	www.exsite.org
Friends of the Earth	www.foe.co.uk
House Builders Federation	www.hbf.co.uk
Institute of Field Archaeologists	www.archaeologists.net
Institute of Petroleum	www.petroleum.co.uk
Institution of Chemical Engineers	www.ichem.org
Institution of Civil Engineers	www.icenet.org
Institute of Environmental Health Officers	www.cieh.org.uk
International Standards Organisation	www.iso.ch

Loss Prevention Council	www.bre.co.uk
National Housing Federation	www.housing.org.uk
National House Builders Council	www.nhbc.co.uk
Old Maps – Historical	www.old-maps.co.uk
Ordnance Survey	www.ordnancesurvey.co.uk
Ordnance Survey Northern Ireland	www.osni.gov.uk
Royal Institute of British Architects	www.riba.org
Royal Institution of Chartered Surveyors	www.rics.org
Scottish Enterprise	www.scottish-enterprise.com
Transport Research Laboratory	www.trl.co.uk
United Kingdom Environmental Law Association	www.ukela.org
Water Research Centre	www.wrcplc.co.uk
Welsh Development Agency	www.wda.co.uk

Virtual construction site

www.leedsmet.ac.uk/teaching/vsite

Appendix B: Additional References

In addition to the further reading at the end of some chapters we have also included some more specific references for readers wishing to go into more depth in specific areas.

Chapter 2

BRE (1995) *Site investigation for low-rise building: direct investigations*, Digest 411, CI/SfB (A3s)

BRE (2000) *Simple foundations for low rise housing: site investigation,* Good Building Guide 39, Part 1, Watford, BRE

BSI (1999) *Code of practice for site investigations*, 5930:1999, London. HMSO

Charles, J.A. and Watts, K.S. (2000) *Building on fill: geotechnical aspects*, *2nd edn*, Watford, BRE

Laider, D. W., Bryce, A.J. and Wilbourn, P. (2002) *Brownfields – managing the development of previously developed land: a client's guide*, London, CIRIA

Chapter 4

CIBSE (1999) *Guide A: Environmental design, Section A3: Thermal properties of building structures,* Chartered Institution of Building Services Engineers

BS EN ISO 13370 (1998) *Thermal performance of buildings – Heat transfer via the ground – calculation methods*, International Standards

Simons, M.W. and Waters, J.R. (2004) *Sound Control in Buildings*, Oxford, Blackwell Publishing

Waters, J.R. (2003) *Energy Conservation in Buildings*, Oxford, Blackwell Publishing

Chapter 5

BRE (1985) *Defects Action Sheet (Design)*, CI/SfB 1976 8 (21) F47) DAS 18, BRE/

BS 5628-3 (1985) *Code of practice for use of masonry. Part 3: Materials and components, design and workmanship*, BSi

Thomas, K. (1996) *Masonry walls, specification and design*, Butterworth Architecture

Chapter 7

BRECSU (1995a) *Energy efficiency in new housing: detailing for designers and building professionals, Good practice guide 95: external cavity walls*, London, HMSO

BRECSU (1995b) *Energy efficiency in new housing: detailing for designers and building professionals, Good practice guide 96: windows and external doors*, London, HMSO

BRECSU (1995c) *Draught stripping of external doors and windows*, Good practice guide 139; London, HMSO

Southwall Technologies (2002) Product information available from http://www. southwall.com/products/ superglass.html (accessed November 18, 2002)

Stephen, R. (2000) *Airtightness in UK Dwellings*, BRE Information Paper IP 1/100. Garson, Watford, Building Research Establishment.

Velux roof windows, Woodside Way, Glenrothes East, KY7 4ND

Chapter 8

BRE (1998) *Fire doors, BRE Digest 320*, Watford, Building Research Establishment

BRE (1987) *Domestic draughtproofing: materials, costs and benefits, BRE Digest 310*, Watford. Building Research Establishment

BRECSU (1995a) *Energy efficiency in new housing: detailing for designers and building professionals, Good practice guide 96: windows and external doors*, London, HMSO

BRECSU (1995b) Draughtstripping of existing doors and windows, *Good Practice Guide 139*, London, HMSO

BRECSU (1996) *Minimising thermal bridging in new dwellings: a detailed guide for architects and building designers, Good Practice Guide 174*, London, HMSO

Chapter 9

NHBC (2000) *Staircases*, NHBC Standards, January 2000, Chapter 6.6

Chapter 11

Littlefair, P. (2001) *Energy efficient lighting: Part L of the Building Regulations explained*, Watford, BRE

Littlefair, P. (1999) Photoelectric control of lighting: design, setup and installation issues, BRE Information Paper IP2/99, Watford, BRE

Scaddan, B. (2002a) *16 IEE Wiring Regulations: explained and illustrated, 6th edn*, Newnes, London

Scaddan, B. (2002b) *16 IEE Wiring Regulations: design and verification of electrical installations, 4th edn*, Newnes, London

Index